ON THE RADIATION FIELDS OF SCATTERED LASER LIGHT BY AN ELECTRON AND STUDY OF ABSORPTION SPECTRUM OF $Dy^{3+}:LaCl_3$

激光被電子散射的輻射場及 $Dy^{3+}: LaCl_3$ 吸收光譜研究

by

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ABSTRACT

The scattered field by the interaction of a laser plane wave with a single electron is studied in the first section. The polarization of the scattered field is important in a free electron laser but seldomly studied. Now, the electric field of the scattered field is derived in terms of the incident plane wave. Both linearly and circularly incident plane waves are considered. As examples, the results of the average intensity along each polarization direction are calculated for some cases. The resultant scattering cross section is calculated too, and is agreeable to some previous results.

In the second section, the absorption spectra of $Dy^{3+}:LaCl_3$ and their Zeeman effect splittings at 4.2K in the ultraviolet region have been studied. The wavelengths were measured and were converted into wavenumbers in vacuum. They are tabulated with polarization and intensity. Also the Zeeman effect of the spectra for magnetic field from zero to about 80 kilogauss were measured and were tabulated and plotted. From these data the energy levels were analyzed. Hence, the empirical energy level scheme for Dy^{3+} ions in crystal $LaCl_3$ has been extended to higher energy region.

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SECTION (A)

LASER INTERACTION WITH MATTER

Chapter 1

INTRODUCTION

Free electron laser is a device to generate coherent radiation by relativistic electrons. In recent years, a lot of effort has been put into the study of free electron laser because of its many advantages.

During the past decade, there were a lot of papers on free electron laser. Both classical and quantum mechanical treatments were used in the studies. However most efforts had been usually contributed in the consideration of the gain or the amplification of the laser. Only a few authors have studied the polarization effects of the electric field in the free electron laser[1,2,3].

Since an accelerating electron will produce radiation, the radiation field in the free electron laser is studied by the classical electrodynamics. In this section, the polarization of the radiation by an electron accelerated by an electromagnetic plane wave is studied, also the intensity effect is considered. The scattering cross section of the plane wave was reported by Chan in 1977 by another approach[4,5].

Because the output power of a free electron laser is proportional to that of a single electron, considering the case for one electron, and then multiplying an effective electron number, one can find the power of a free electron laser. Hence, we have considered the scattering radiation field of a single electron and found the distribution of intensity along both polarization directions.

In the following chapter, a brief description of the electron dynamics will be presented. From the basic force law, the Lorentz force law, the motion of the electron is studied. Due to the influence of an incident plane wave, the momenta and trajectory of the electron are solved in a general form. Then the scattered electromagnetic field is considered in chapter 3. In that chapter, starting from the Lienard-Wiechert field, the scattered field of the incident plane wave is solved in terms of the retarded time, the latitude and longitude angle of an observation position. In chapter 4 the calculated results are presented. Here some particular cases are calculated and angular distribution of the intensity along each polarization is given for different parameters.

Chapter 2

THE MOTION OF ELECTRON

In order to study the interaction of a laser pulse (considered as an electromagnetic plane wave) with matter (as in the simplest form : an electron), one can investigate the motion of an electron influenced by an electromagnetic plane wave. Since electromagnetic plane wave is polarized; two simplest cases - linearly and circularly polarized, are considered. In the following part, a free electron influenced by either one will be discussed.

Consider an electron of rest mass m and charge e in an electromagnetic plane wave of electric field $\vec{E}$ and magnetic induction $\vec{B}$. Suppose the plane wave is propagating along direction $\vec{n}$, then $\vec{E} = \vec{E}(\tau)$ and $\vec{B} = \vec{n} \times \vec{E}$ in which $\tau = t - \vec{R}\cdot\vec{v}/c$ is the retarded time. Consider the polarization direction is $\vec{m}$, then $\vec{E}(\tau) = E(\tau)\vec{m}(\tau)$. Hence

$$\vec{F} = \frac{e\vec{E}}{\delta} + e(\vec{\beta}\cdot\vec{E})\vec{n} \qquad (2\text{-}1)$$

where $\delta = (1-\vec{n}\cdot\vec{\beta})^{-1}$ is the Doppler factor and $c\vec{\beta}$ is the velocity of the electron.

2.1 Electron dynamics

The equation of motion of the electron are given by,

$$\frac{d\vec{p}}{dt} = \frac{e\vec{E}}{\delta} + e(\vec{\beta}\cdot\vec{E})\vec{n} \tag{2-2a}$$

$$\frac{d\mathcal{E}}{dt} = ec\vec{\beta}\cdot\vec{E} \tag{2-2b}$$

or in the components form,

$$\frac{d\vec{p}_m}{dt} = \frac{e}{\delta}E(\tau)\vec{m}(\tau) \tag{2-3a}$$

$$\frac{dp_n}{dt} = eE(\tau)\vec{\beta}\cdot\vec{m}(\tau) = eE(\tau)\beta_m(\tau) \tag{2-3b}$$

$$\frac{d\mathcal{E}}{dt} = ec\beta_m E(\tau) \tag{2-3c}$$

where $\vec{p} = mc\gamma\vec{\beta}$ is the momentum of the electron, $\mathcal{E} = mc^2\gamma$ is the total energy, γ is the Lorentz factor and $\vec{p}_m$, p_n are the perpendicular and parallel component of $\vec{p}$ with respect to $\vec{n}$ direction.

Relativistically the differential proper time ds is defined by dt/γ , hence (2-3) is rewritten as,

$$\frac{d\vec{p}_m}{ds} = \frac{e\gamma}{\delta}E(\tau)\vec{m}(\tau) \tag{2-4a}$$

$$\frac{dp_n}{ds} = \frac{eE(\tau)}{mc}p_m \tag{2-4b}$$

$$\frac{d\mathcal{E}}{ds} = \frac{eE(\tau)}{m}p_m \tag{2-4c}$$

From (2-4b) and (2-4c) it is directly found that

$$\frac{d}{ds}(cp_n-\mathcal{E}) = 0 \tag{2-5}$$

i.e. $cp_n-\mathcal{E}$ is a constant of motion. Hence $mc^2\gamma(\beta_n-1)$, or γ/δ is constant. Hence we have a constant of motion $\alpha = \gamma/\delta$. If the electron is at rest initially, $\alpha=1$ otherwise $\alpha = \gamma_o/\delta_o$.

Because the differential proper time ds and differential retarded time $d\tau$ are given by

$$ds = \frac{dt}{\gamma} \tag{2-6a}$$

$$d\tau = \frac{dt}{\delta} \quad . \tag{2-6b}$$

Hence $d\tau = \alpha ds$. (2-7)

Substituting (2-7) into (2-4), we have

$$\vec{p}_m(\tau)-\vec{p}_{m,o} = e\int_o^{\tau} E(\tau)\vec{m}(\tau)d\tau \tag{2-8a}$$

$$p_n(\tau)-p_{n,o} = \frac{1}{2mc\alpha}(p_m^2(\tau)-p_{m,o}^2) \quad . \tag{2-8b}$$

Due to (1-5), we have

$$\mathcal{E}(\tau)-\mathcal{E}_o = cp_n(\tau)-cp_{n,o} \quad . \tag{2-8c}$$

After $p_n(\tau)$, $p_m(\tau)$ are known, we can obtain the trajcetory of the electron by $\vec{\beta}= \vec{p}/mc\gamma$.

2.2 Linearly polarized wave

If the incident plane wave is linearly polarized, then $\vec{E}(\tau) = E_o\cos(\omega\tau)\vec{i}$; i.e. magnitude dependenting on time as a cosine and polarization is a constant unit vector. Also assuming the electron is travelling along direction $\vec{n}$ with a velocity $c\vec{\beta}_o$ initially, straight forward we have the solution from

(2-8),

$$p_m(\tau) = \frac{eE_o}{\omega}\sin(\omega\tau) \tag{2-9a}$$

$$p_n(\tau)-p_{n,o} = \frac{e^2E_o^2}{2mc\alpha\omega^2}\sin^2(\omega\tau) \tag{2-9b}$$

$$\mathcal{E}-\mathcal{E}_o = \frac{e^2E_o^2}{2m\alpha\omega^2}\sin^2(\omega\tau) \quad . \tag{2-9c}$$

Because of $\mathcal{E} = \mathcal{E}_K + mc^2$, we have

$$\mathcal{E}_K-\mathcal{E}_{K,o} = \frac{e^2E_o^2}{2m\alpha\omega^2}\sin^2(\omega\tau) \quad . \tag{2-9d}$$

Defining the normalized kinetic energy as

$$\epsilon_K(\tau) = \frac{\mathcal{E}_K(\tau)}{mc^2} \tag{2-10}$$

then, $\epsilon_K(\tau)-\epsilon_{K,o} = 2\overline{\Delta\epsilon}_K\sin^2(\omega\tau)$ with $\overline{\Delta\epsilon}_K$ as the time average of $\epsilon_K(\tau)-\epsilon_{K,o}$;

$$\overline{\Delta\epsilon}_K = \frac{1}{\alpha}\left(\frac{eE_o}{2mc\omega}\right)^2 \quad . \tag{2-11}$$

Also we have the normalized momenta,

$$\frac{p_m}{mc} = \frac{eE_o}{mc\omega}\sin(\omega\tau) = 2\sqrt{\alpha\overline{\Delta\epsilon}_K}\sin(\omega\tau) \tag{2-12a}$$

$$\frac{p_n}{mc} = \gamma_o\beta_o + 2\overline{\Delta\epsilon}_K\sin^2(\omega\tau) \quad . \tag{2-12b}$$

By defining $\vec{\rho} = \vec{r}/c$, then $\vec{\beta} = d\vec{\rho}/dt$. Suppose the electron is in the origin initially, then $\rho_o = 0$, from (2-6),

$$\alpha\frac{d\rho_m}{d\tau} = 2\sqrt{\alpha\overline{\Delta\epsilon}_K}\sin(\omega\tau) \tag{2-13a}$$

$$\alpha\frac{d\rho_n}{d\tau} = \gamma_o\beta_o + 2\overline{\Delta\epsilon}_K\sin^2(\omega\tau) \tag{2-13b}$$

After integrating (2-13), the trajectory of the electron is solved,

$$\rho_m(\tau) = \frac{2}{\omega}\sqrt{\frac{\overline{\Delta\epsilon}_K}{\alpha}}(1-\cos(\omega\tau)) \tag{2-14a}$$

$$\rho_n(\tau) = \frac{\gamma_0\beta_0+\overline{\Delta\epsilon}_K}{\alpha}\tau - \frac{\overline{\Delta\epsilon}_K\sin(2\omega\tau)}{2\omega\alpha} \tag{2-14b}$$

Hence, along the direction of the propagation the electron is in motion of uniform velocity plus an oscillation which frequency is double of the plane wave frequency. Also one can find the uniform velocity is contributed by the initial condition $\gamma_0\beta_0 c/\alpha$ and the plane wave $\overline{\Delta\epsilon}_K c/\alpha$. The transverse displacement is also an oscillation with the frequency same as the plane wave. The motion is similar to a forced harmonic motion due to the electric field.

2.3 Circularly polarized wave

Consider a circularly polarized incident wave with its electric field $\vec{E}(\tau)=E_0(\cos(\omega\tau)\vec{i} + \sin(\omega\tau)\vec{j})$, i.e. a unit vector rotating on the x-y plane. Also the electron is assumed initially travelling along $\vec{n}$ with $c\vec{\beta}_0$. It is convenient to use complex representation,

$$\hat{E}(\tau) = E_0 e^{i\omega\tau}$$
$$\hat{p}_m(\tau) = p_x(\tau) + ip_y(\tau) \tag{2-15}$$

By solving (2-8),

$$\hat{p}_m(\tau) = \frac{2eE_0}{\omega}\exp(i\frac{\omega\tau}{2})\sin(\frac{\omega\tau}{2}) \tag{2-16a}$$

$$p_n(\tau)-p_{n,o} = \frac{2e^2E_o^2}{\omega^2 mc\alpha}\sin^2\left(\frac{\omega\tau}{2}\right) \qquad (2\text{-}16b)$$

$$\mathcal{E}_K(\tau)-\mathcal{E}_{K,o} = \frac{2e^2E_o^2}{\omega^2 m\alpha}\sin^2\left(\frac{\omega\tau}{2}\right) \qquad (2\text{-}16c)$$

for vector $\vec{p}_m(\tau)$, the length is the norm of $\hat{p}_m(\tau)$,

$$p_m(\tau) = \frac{2eE_o}{\omega}\sin\left(\frac{\omega\tau}{2}\right) \qquad (2\text{-}16a')$$

Similarly the normalized kinetic energy defined by (2-10),

$$\epsilon_K(\tau)-\epsilon_{K,o} = 2\overline{\Delta\epsilon}_K\sin^2\left(\frac{\omega\tau}{2}\right) \qquad (2\text{-}17)$$

but note that now, $\overline{\Delta\epsilon}_K$ has changed as

$$\overline{\Delta\epsilon}_K = \frac{1}{\alpha}\left(\frac{eE_o}{mc\omega}\right)^2 \qquad (2\text{-}18)$$

which is four times of that in the linear case.

Then the normalized momenta are obtained as,

$$\frac{p_m(\tau)}{mc} = \frac{2eE_o}{mc}\sin\left(\frac{\omega\tau}{2}\right) = 2\sqrt{\alpha\overline{\Delta\epsilon}_K}\sin\left(\frac{\omega\tau}{2}\right) \qquad (2\text{-}19a)$$

$$\frac{p_n(\tau)}{mc} = \gamma_o\beta_o + 2\overline{\Delta\epsilon}_K\sin^2\left(\frac{\omega\tau}{2}\right) \qquad (2\text{-}19b)$$

Compare (2-19) with (2-12), we have the same form of normalized momenta for both cases. To describe the momenta and kinetic energy of the electron, one can use parameter $\overline{\Delta\epsilon}_K$, which is related to the magnitude of the incident plane wave E_o and frequency ω . Table 2-1 gives the comparison.

Table 2-1

Polarization of the incident plane wave

	(Linear)	(Circular)
Inc.wave	$E_o \cos(\omega\tau)\vec{i}$	$E_o(\cos(\omega\tau)\vec{i}+\sin(\omega\tau)\vec{j})$
Parameter	$\overline{\Delta\epsilon}_K = \frac{1}{\alpha}(\frac{eE_o}{2mc\omega})^2$	$\overline{\Delta\epsilon}_K = \frac{1}{\alpha}(\frac{eE_o}{mc\omega})^2$
Normalized K.E.	$2\overline{\Delta\epsilon}_K \sin^2(\omega\tau)$	$2\overline{\Delta\epsilon}_K \sin^2(\frac{\omega\tau}{2})$
Normalized momenta	$\frac{p_m(\tau)}{mc} = 2\sqrt{\alpha\overline{\Delta\epsilon}_K}\sin\theta;\ \frac{p_n(\tau)}{mc} = \gamma_o\beta_o + 2\overline{\Delta\epsilon}_K\sin^2\theta$	
	$\theta = \omega\tau$	$\theta = \omega\tau/2$

The trajectory of the electron for this case is solved. From (2-19b) we have the same solution ρ_n as (2-14b) except replacing $\omega\tau$ by $\omega\tau/2$,

$$\rho_n(\tau) = \frac{\gamma_o\beta_o+\overline{\Delta\epsilon}_K}{\alpha}\tau - \frac{\overline{\Delta\epsilon}_K\sin(\omega\tau)}{\omega\alpha} \quad . \tag{2-20}$$

Since $\hat{\rho}_m = \rho_x + i\,\rho_y$, $\hat{\rho}_m(\tau)$ can be solved directly from (1-16a)

$$\hat{\rho}_m(\tau) = \frac{1}{\omega}\sqrt{\frac{\overline{\Delta\epsilon}_K}{\alpha}}\left[(1-e^{i\omega\tau})+i\omega\tau\right] \tag{2-21}$$

or
$$\rho_x(\tau) = \frac{1}{\omega}\sqrt{\frac{\overline{\Delta\epsilon}_K}{\alpha}}(1-\cos(\omega\tau)) \tag{2-22}$$

$$\rho_y(\tau) = \sqrt{\frac{\overline{\Delta\epsilon}_K}{\alpha}}(\tau-\frac{\sin(\omega\tau)}{\omega}) \tag{2-23}$$

Along the propagation direction of the plane wave, the electron moves the same way as in the linear case, that is a uniform motion plus an oscillation. However the frequency of the oscillation is the same as the electromagnetic wave. Moreover, since the electric field of the wave has two transverse components, we can solve two transverse displacements too. Both are oscillations of frequency same as the field.

Chapter 3

SCATTERING ELECTROMAGNETIC FIELD BY AN ELECTRON

3.1 Field produced by an electron driven by a force

An accelerating charge will produce radiation; energy is radiated to the surrounding. This is a well known result in classical electrodynamics[6,7]. The field produced by a moving charge is dependent on the retarded time $\tau = t - \vec{R}\cdot\vec{v}/c$; the retarded field is known as the Lienard-Wiechert field. There are two parts in the field, however only the acceleration field is radiation. Due to the accelerated motion of an electron, the radiation field is given by the acceleration field of Lienard-Wiechert field,

$$\vec{E}_r(\tau) = \frac{e}{cR}\left\{\frac{\vec{n}'\times((\vec{n}'-\vec{\beta})\times\dot{\vec{\beta}})}{(1-\vec{n}'\cdot\vec{\beta})}\right\}_{ret} \tag{3-1}$$

where $\vec{n}'$ is the unit vector of position vector $\vec{R}$, or the propagating direction of the radiation; $c\vec{\beta}$ and $c\dot{\vec{\beta}}$ are the velocity and acceleration of the electron respectively.

Suppose a force $\vec{F}$ is applied on the electron and causes it to accelerate. Then the relativistic force law is given by

$$\vec{F} = mc\frac{d}{dt}(\gamma\vec{\beta}) \tag{3-2}$$

or

$$\vec{F} = mc\gamma(\dot{\vec{\beta}}+\gamma^2\vec{\beta}(\vec{\beta}\cdot\dot{\vec{\beta}})). \tag{3-3}$$

Hence, the acceleration of the electron due to a force $\vec{F}$ is expressed as

$$\dot{\vec{\beta}} = \frac{1}{mc\gamma}(\vec{F}-\vec{\beta}(\vec{\beta}\cdot\vec{F})) \tag{3-4}$$

Substituting (3-4) into (3-1) yields the radiation field of the electron due to the influence of an arbitary force,

$$\vec{E}_r(\tau) = \frac{e\delta'^2}{mc^2R}\left\{\delta'(\vec{n}'\cdot\vec{F}-\vec{\beta}\cdot\vec{F})(\vec{n}'-\vec{\beta})-\vec{F}+\vec{n}'(\vec{\beta}\cdot\vec{F})\right\} \tag{3-5}$$

in which the factor δ' is the Doppler factor for the vector $\vec{n}'$,

$$\delta' = (1-\vec{n}'\cdot\vec{\beta})^{-1} \tag{3-6}$$

3.2 Scattering electromagnetic wave by an electron

If the electron is pushed by an electromagnetic plane wave, then it is drived by the electromagnetic force and radiates; the radiation field is called the scattering field of the incident electromagnetic plane wave. Since the force in (3-5) is arbitary, one can apply (3-5) to find the scattering field for this electromagnetic force.

Suppose the electron is travelling along the direction coincident to the propagating direction of the electromagnetic plane wave $\vec{n}$, and its velocity is $c\vec{\beta}_o$. Hence, the constant $\alpha = \gamma_o(1-\beta_o)$. The electric field of the electromagnetic plane wave is polarized,

$$\vec{E}(\tau) = E(\tau)\vec{m}(\tau) \tag{3-7}$$

Due to the influence of this electromagnetic plane wave, the electron is drived by a force given as,

$$\vec{F}(\tau) = e\left[\vec{E}(\tau)+\vec{\beta}\times(\vec{n}\times\vec{E}(\tau))\right] \tag{3-8}$$

or

$$\vec{F}(\tau) = \frac{e}{\delta}\vec{E}(\tau)+e(\vec{\beta}\cdot\vec{E}(\tau))\vec{n} \tag{3-9}$$

Substituting force (3-9) into (3-5), directly the field is,

$$\begin{aligned}\vec{E}_r(\tau) = \frac{e^2E(\tau)\delta'^2}{mc^2R\gamma\delta}\Big\{&\Big[\delta'\vec{n}'\cdot\vec{m}-\frac{\delta' p_m}{mc\alpha}(1-\vec{n}'\cdot\vec{n})+\frac{p_m}{mc\alpha}\Big]\vec{n}'-\Big[1\\ &+\frac{\delta' p_m}{mc\alpha}\Big(\vec{n}'\cdot\vec{m}-\frac{\delta p_m}{mc\gamma}(1-\vec{n}'\cdot\vec{n})\Big)\Big]\vec{m}-\Big[\frac{\delta p_m}{mc\gamma}+\frac{\delta' p_n}{mc\gamma}\Big(\vec{n}'\cdot\vec{m}-\frac{\delta p_m}{mc\gamma}(1-\vec{n}'\cdot\vec{n})\Big)\Big]\vec{n}\Big\}\end{aligned} \tag{3-10}$$

in which, p_m and p_n are short hand for $\vec{p}\cdot\vec{m}$ and $\vec{p}\cdot\vec{n}$, the transverse and parallel momentum of the electron. In a more compact form, by adoption of some convenient notations, (3-10) may be rewrirten,

$$\vec{E}_r(\tau) = \frac{r_o E(\tau)}{\alpha^2 R}\left(\frac{\delta'}{\delta}\right)^2(\delta' N'\vec{n}'+M\vec{m}+N\vec{n}) \tag{3-11}$$

in which $r_o = e^2/mc^2$ is the classical electron radius; M, N defined as

$$M = -\alpha\left(1+\frac{p_m}{mc\alpha}\left(\frac{\delta'}{\delta}\right)\Phi\right) \tag{3-12a}$$

$$N = -\left(\frac{p_m}{mc}+\frac{p_n}{mc}\left(\frac{\delta'}{\delta}\right)\Phi\right) \tag{3-12b}$$

with

$$\Phi = \vec{n}'\cdot\vec{m}-\frac{p_m}{mc\alpha}(1-\vec{n}'\cdot\vec{n}) \ . \tag{3-12c}$$

In (3-12), p_m/mc and p_n/mc are the normalized momentra which are solved by electron dynamics, as (2-12) and (2-

16) for the incident plane wave linearly or circularly polarized respectively.

The factor δ'/δ is the ratio of the Doppler factors for $\vec{n}$ and $\vec{n}'$. By definition,

$$\frac{\delta'}{\delta} = \frac{1-\vec{n}\cdot\vec{\beta}}{1-\vec{n}'\cdot\vec{\beta}} \tag{3-13}$$

Since total energy is given by $\gamma = \epsilon_K + 1$ and apply (2-8), it can be expressed as

$$\frac{\delta'}{\delta} = \alpha\left(\alpha-\vec{n}'\cdot\vec{m}\frac{p_m}{mc}+(1-\vec{n}'\cdot\vec{n})\frac{p_n}{mc}\right)^{-1} \tag{3-14}$$

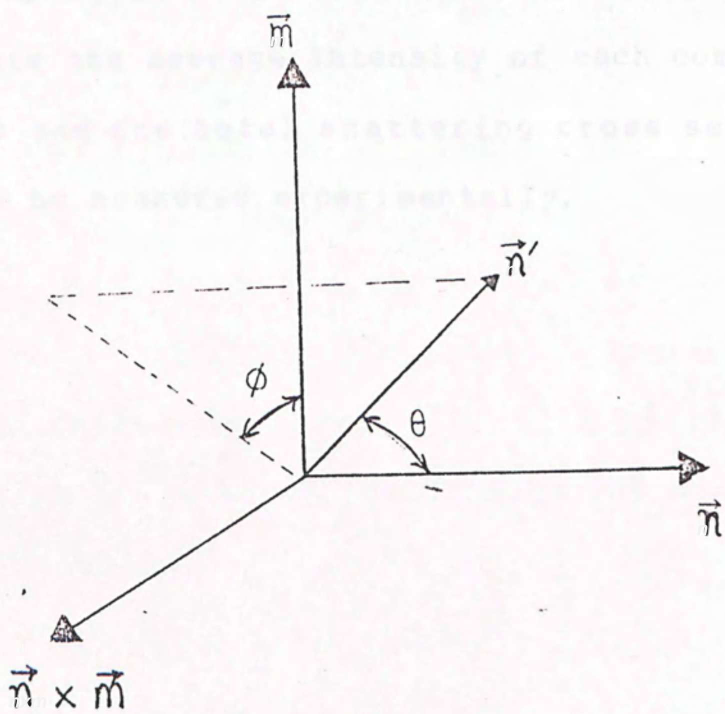
Hence the scattering field is dependent on the retarded time and observation position $\vec{R}$. The 1/R dependence means it is a spherical wave and the time dependence is much complicated.

For a vector, we can span it by a set of basis vector. In (3-11), the electric field vector is spanned by ($\vec{n}'$, $\vec{n}$, $\vec{m}$) with corresponding components N', N and M. However this set is not an orthornomal one; we replace it by a more convenient set,

$$\begin{aligned} \vec{n}' &= \cos\theta\vec{n} + \sin\theta\cos\phi\vec{m} - \sin\theta\sin\phi(\vec{n}\times\vec{m}) \\ \vec{\varepsilon}_1 &= -\sin\theta\vec{n} + \cos\theta\cos\phi\vec{m} + \cos\theta\sin\phi(\vec{n}\times\vec{m}) \\ \vec{\varepsilon}_2 &= -\sin\phi\vec{m} + \cos\phi(\vec{n}\times\vec{m}) \end{aligned} \tag{3-15}$$

where θ , ϕ are the colatitude and longitude of the spherical coordinates of $\vec{n}'$ with respect to $\vec{n}$ and $\vec{m}$ (as shown in figure 3-1), hence $\vec{n}\cdot\vec{n}' = \cos\theta$ and $\vec{m}\cdot\vec{n}' = \sin\theta\cos\phi$. The set of basis vector ($\vec{n}'$, $\vec{\varepsilon}_1$, $\vec{\varepsilon}_2$) may be considered as a rotation of the frame ($\vec{i}$, $\vec{j}$, $\vec{k}$).

Figure 3-1



In terms of this new basis, we have

$$\vec{E}_r(\tau) = \frac{r_o E(\tau)}{R\alpha^2}\left(\frac{\delta'}{\delta}\right)^2\left\{\left[M\cos\theta\cos\phi - N\sin\theta\right]\vec{\varepsilon}_1 + \left[-M\sin\phi\right]\vec{\varepsilon}_2\right\} \quad (3\text{-}16)$$

which is propagating along direction $\vec{n}'$.

In the following chapter, we will discuss the $\vec{E}_r(\tau)$ while the incident plane wave is linearly and circularly polarized. Because the frequency is so high that the electric field cannot be detected, we will try to investigate the average intensity of each component $\langle E_1^2\rangle$ and $\langle E_2^2\rangle$ and the total scattering cross section, all of which can be measured experimentally.

Chapter 4

SCATTERING OF LASER LIGHT

Considering that the high intensity laser light is a polarized plane electromagnetic wave, one may study the interaction of such plane wave with a single electron. Let the propagating direction of the plane wave be n; since the plane wave is polarized, let $\vec{m}$ be the polarization direction. As discussed in section 2.1, $\vec{m}$ is a constant unit vector for linearly polarized wave and a rotating unit vector for circularly polarized wave. The single electron is either at rest or moving along $\vec{n}$ axis initially; for the latter case the initial velocity is represented by $c\vec{\beta}_0$. If the electron in moving towards the plane wave relatively, then $\beta_0 < 0$; otherwise the moving direction is the same as the propagating direction of the plane wave.

4.1 Scattering field of a linearly polarized plane wave

Suppose the electron is at rest initially. Use the set of unit vectors given in (3-15), and now $\vec{m} = \vec{i}$,

$$\vec{\varepsilon}_1 = \cos\theta\cos\phi\vec{i}+\cos\theta\sin\phi\vec{j}-\sin\theta\vec{n} \qquad (4\text{-}1a)$$

$$\vec{\varepsilon}_2 = -\sin\phi\vec{i}+\cos\phi\vec{j} \qquad (4\text{-}1b)$$

to describe the scattering electric field which is propagating along $\vec{n}'$,

$$\vec{n}' = \sin\theta\cos\phi\vec{i}+\sin\theta\sin\phi\vec{j}+\cos\theta\vec{n} \quad . \qquad (4-2)$$

The two components along $\vec{\varepsilon}_1$ and $\vec{\varepsilon}_2$, i.e. E_1 and E_2 are given by (3-16); in which there is one important parameter $\overline{\Delta\epsilon}_K$, given by (2-11). Since the electron is at rest initially, that is $\epsilon_{K,o}=0$; hence $\overline{\Delta\epsilon}_K$ is correponding to the maximum amplitude of the electric field of the incident laser light. For Nd-glass laser, $\lambda=1.06\mu$, then $E_o=6.1\times10^9$ and 1.9×10^{10} volt/cm for $\overline{\Delta\epsilon}_K=0.01$ and 0.1.

It can be shown that directly from (3-16) the scattered field is still linearly polarized for cases $\theta=0°$ and 180°, also for $\phi=0°$. The electric field vector will move on the ploarization plane for each θ and ϕ. Figure 4-1(a) to 4-1(d) show the loci of the electric field vector rotating on the polarization plane in one period. But it must be noted that the polarization planes are different for each θ. Obviously when $\overline{\Delta\epsilon}_K$ is reduced to zero, the field becomes linearly polarized on $\vec{\varepsilon}_2$ for $\theta=90°$; this is just the Thomson scattering field.

However, since the frequency of the field is so high that no detector can observe the field strength, one can only detect the average intensity of each polarizatioan. That is acheived by a polarizer and an intensity detector. Figure 4-2 and 4-3 show normalized distribution of intensity along each polarization direction against angle θ for $\overline{\Delta\epsilon}_K = 0.01$ and 0.1. We can see that it is linearly polarized for $\theta=0^\circ$, i.e. there is only one component. For $\phi=90^\circ$, the intensity is concentrated at the forward direction, it is the resultant effect of the relativistic motion of the electron.

For the situation when the electron has an initial velocity which has only one component parallel to $\vec{n}$, we can calculate the electric field by (3-16). As an example, consider that the electron travels towards the laser plane wave with half of speed of light initaially, then $\beta_0=-0.5$. The initial kinetic energy is about 80keV. Hence we can find the movement of the electric field vector on the polarization plane in one period, which shown in figure 4-4(a) to 4-4(c) are for cases $\theta=90^\circ$, $\phi=90^\circ$ and $\overline{\Delta\epsilon}_K=0.01$, 0.1 and 1 respectively. Directly from the expression (3-16), we can find that the polarization does not change for $\theta=0^\circ$, 180° or $\phi=0^\circ$. From figure 4-4 we can see that the pattern is similar to the previous ones.

In order to fit the experimental work and compare with the rest case, the intensity distribution along both polarization directions, $\langle E_1{}^2\rangle$ and $\langle E_2{}^2\rangle$ are plotted in figure 4-5 and 4-6 against θ. They show most part of the intensity of either direction is skew to the direction of large θ. Since the electron is travelling towards the plane wave relativistically, the intensity is concentrated to the forward direction of the motion, i.e. the large θ region. Consider the opposite case, that the

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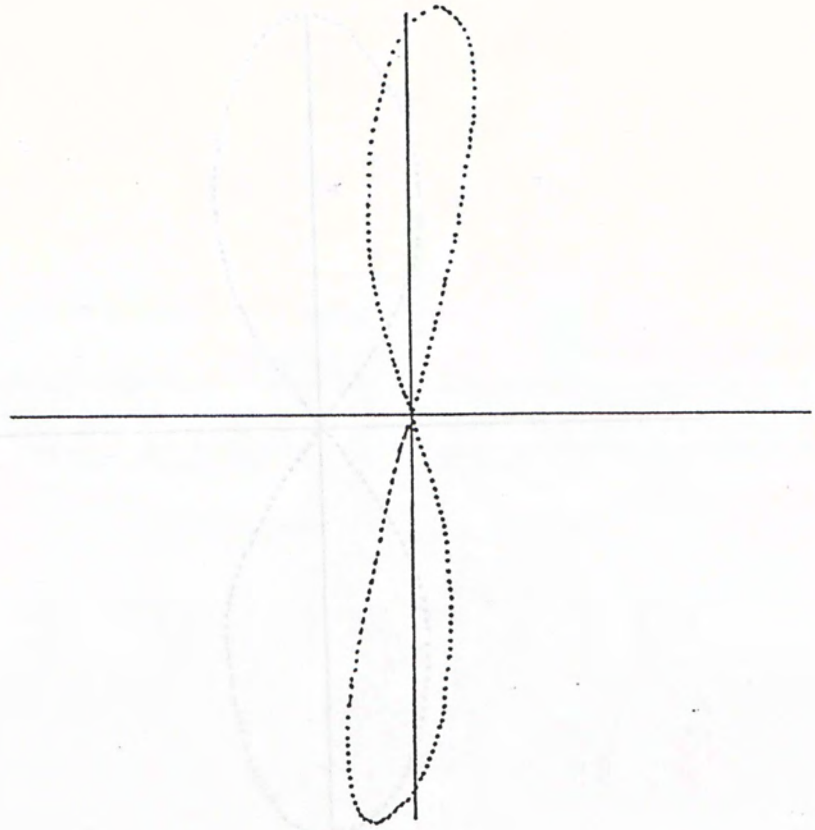


Figure 4-1(a) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.01$ $\theta=90^\circ$ $\phi=45^\circ$

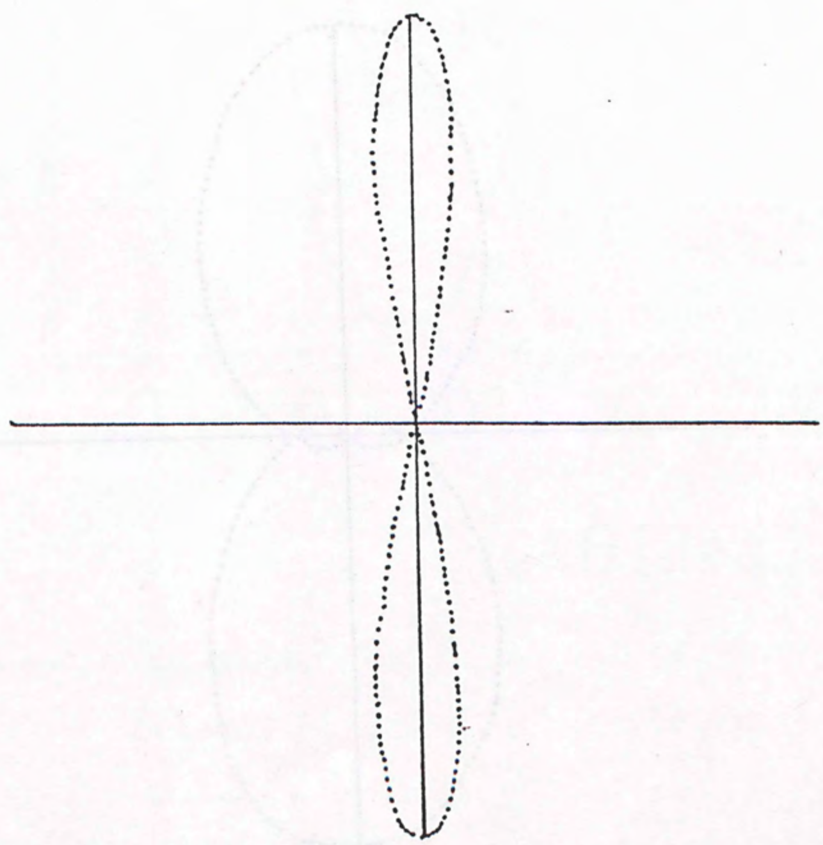


Figure 4-1(b) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.01$ $\theta=90^\circ$ $\phi=90^\circ$

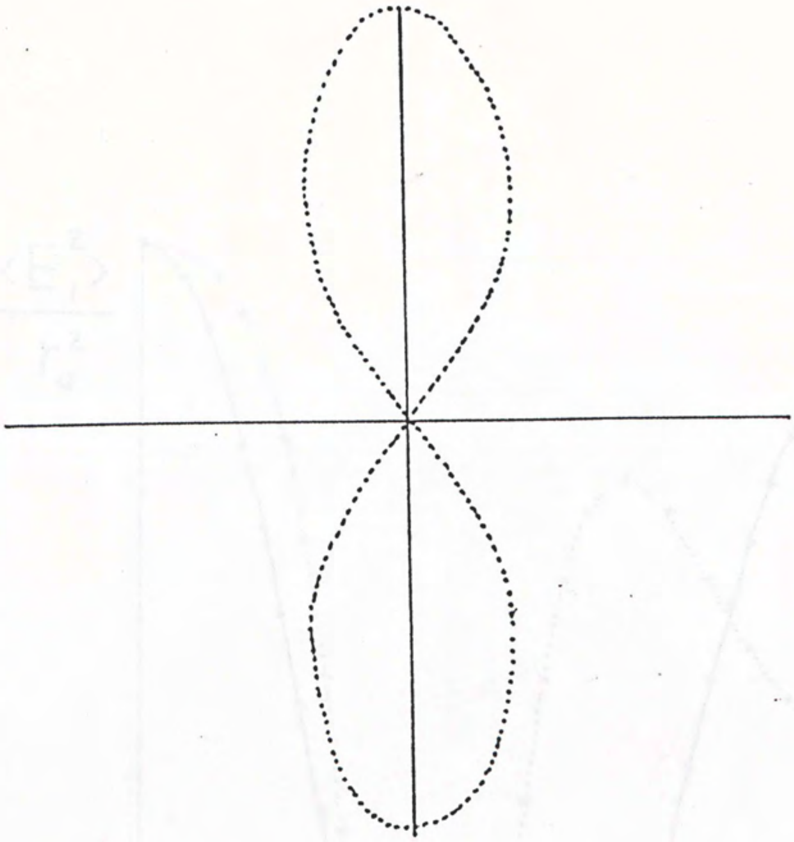


Figure 4-1(c) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.1$ $\theta=90°$ $\phi=90°$

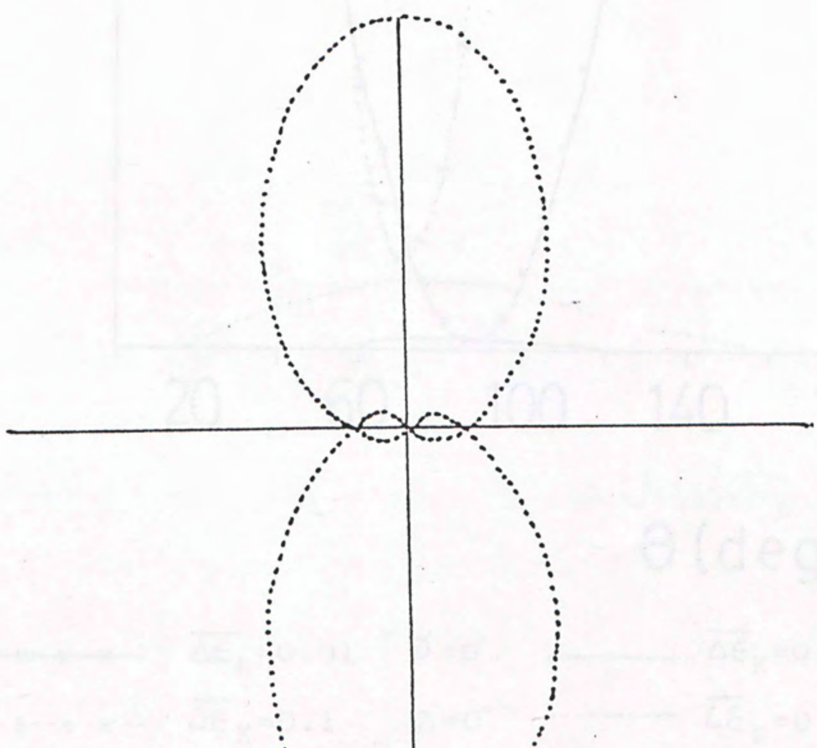
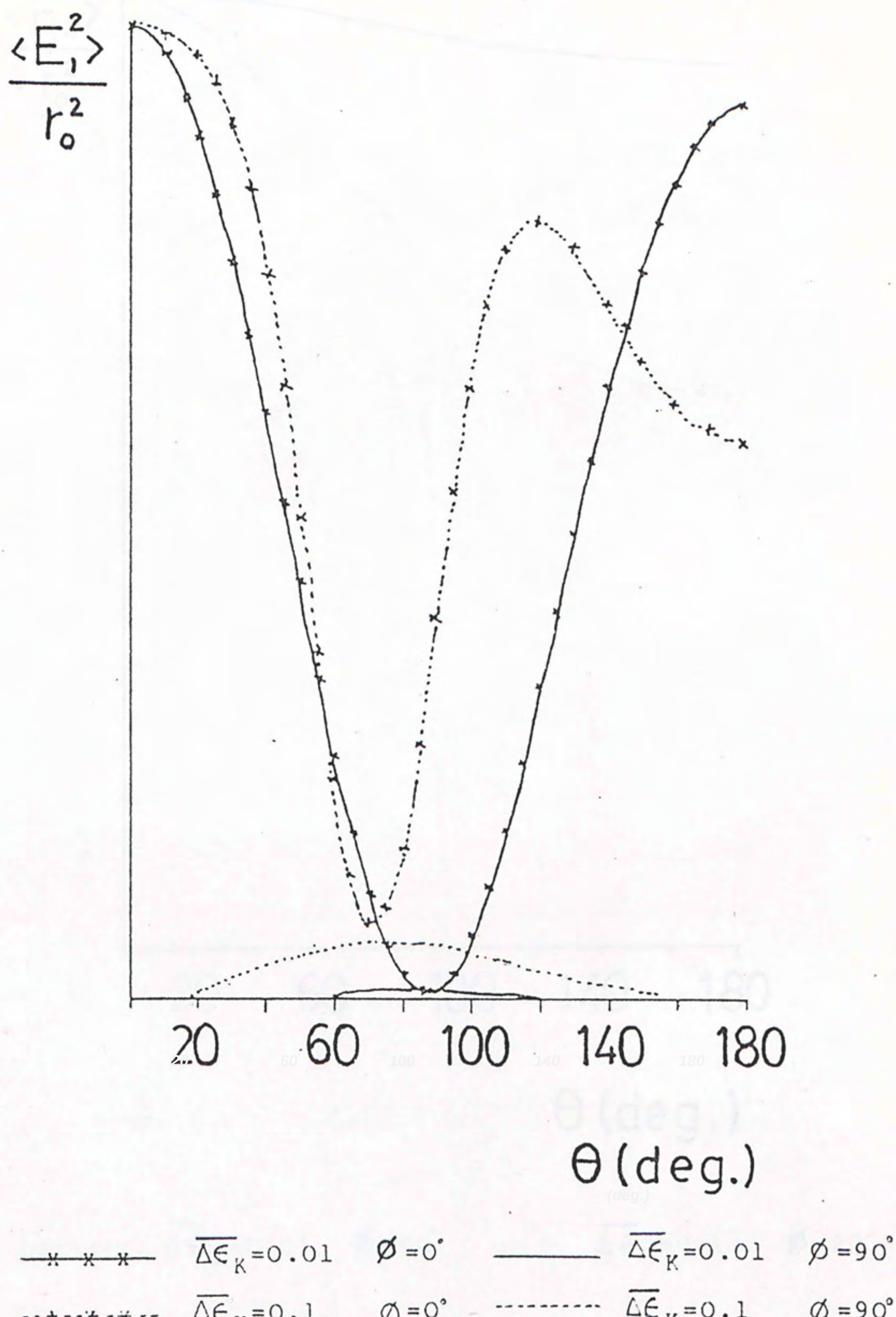
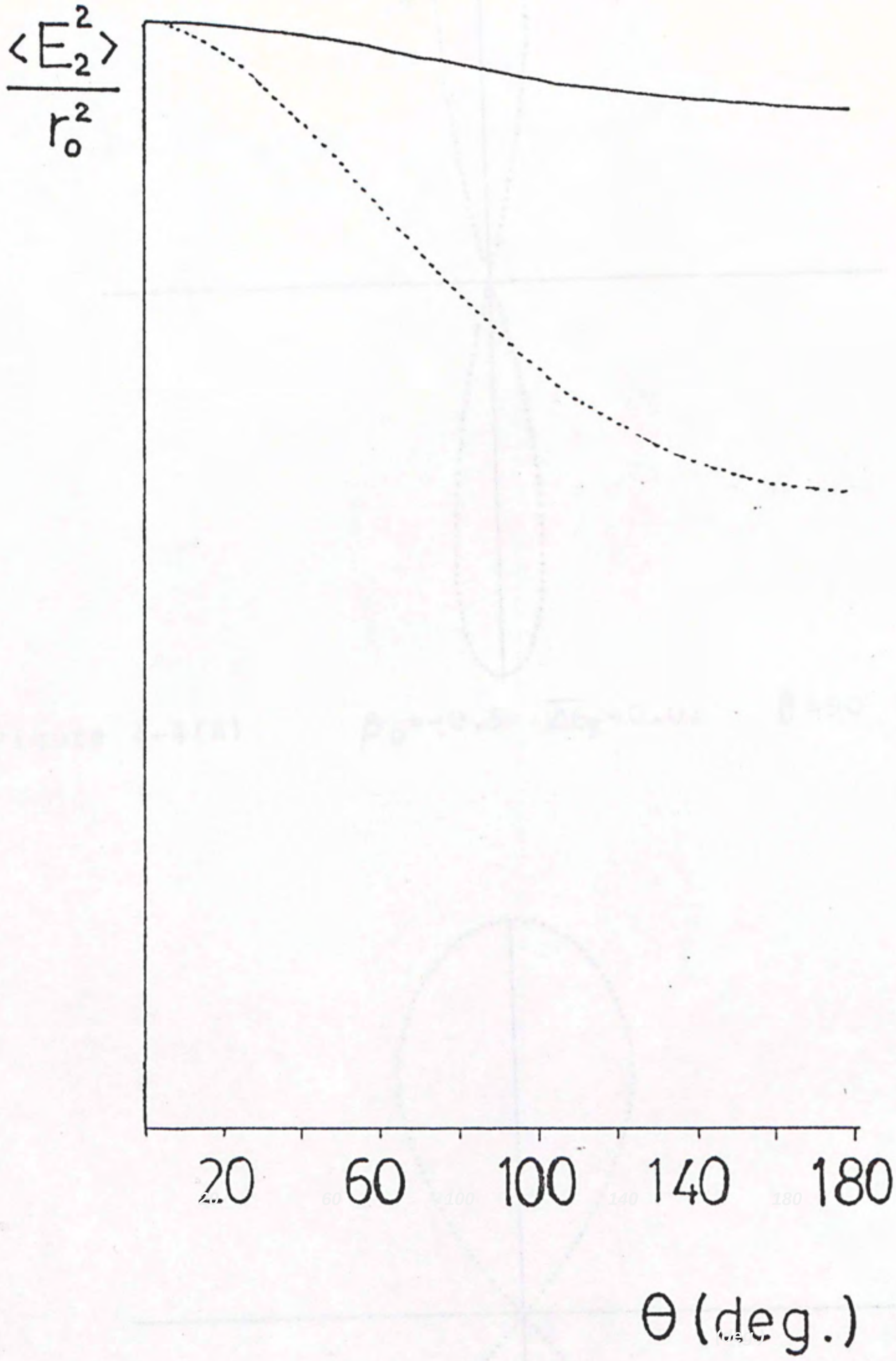


Figure 4-1(d) $\beta_o=0$ $\overline{\Delta\epsilon}_K=1$ $\theta=90°$ $\phi=90°$



$\frac{\langle E_1^2 \rangle}{r_0^2}$
20
60
100
140
180
θ (deg.)
$\overline{\Delta\epsilon}_K=0.01$ $\phi=0°$
$\overline{\Delta\epsilon}_K=0.01$ $\phi=90°$
$\overline{\Delta\epsilon}_K=0.1$ $\phi=0°$
$\overline{\Delta\epsilon}_K=0.1$ $\phi=90°$

Figure 4-2



——— $\overline{\Delta\epsilon}_K=0.01$ $\phi=90°$ ········ $\overline{\Delta\epsilon}_K=0.1$ $\phi=90°$

Figure 4-3

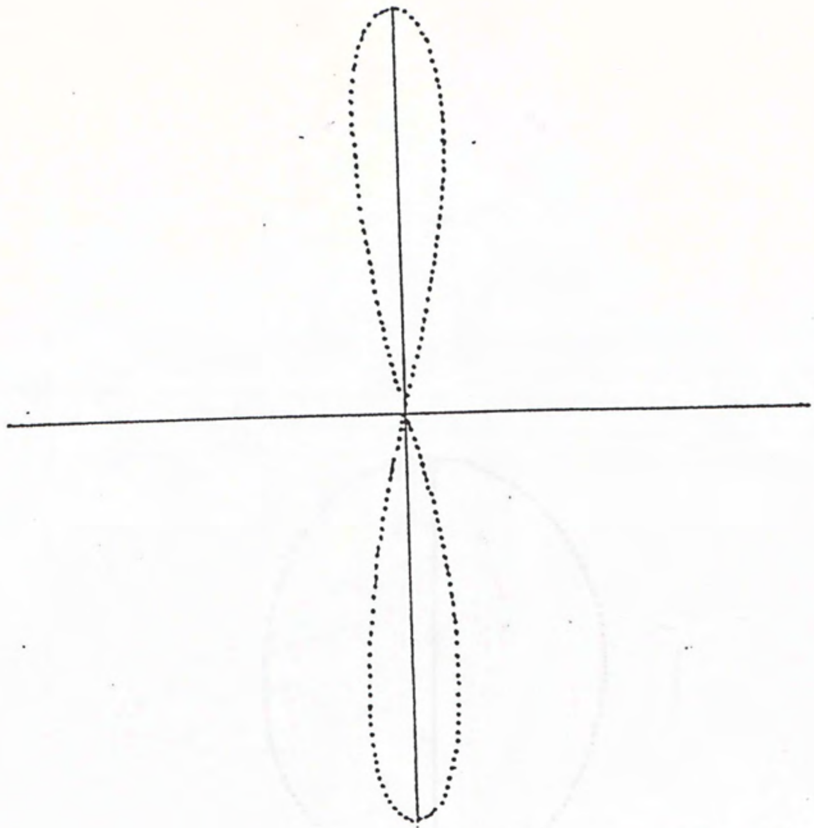


Figure 4-4(a) $\beta_o=-0.5$ $\overline{\Delta\epsilon}_K=0.01$ $\theta=90^\circ$ $\phi=90^\circ$

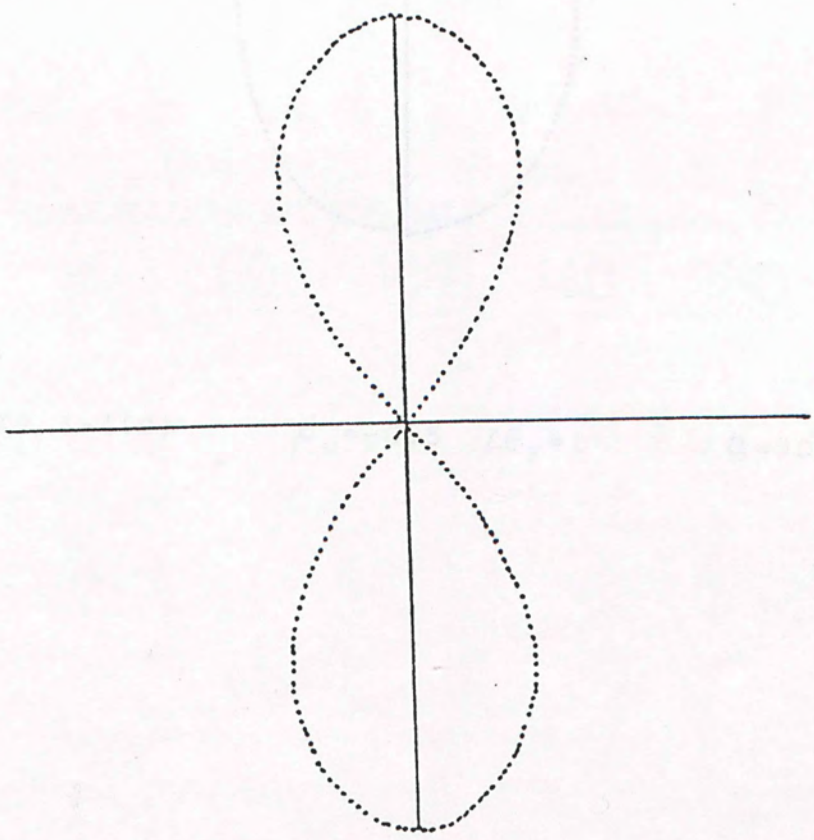


Figure 4-4(b) $\beta_o=-0.5$ $\overline{\Delta\epsilon}_K=0.1$ $\theta=90^\circ$ $\phi=90^\circ$

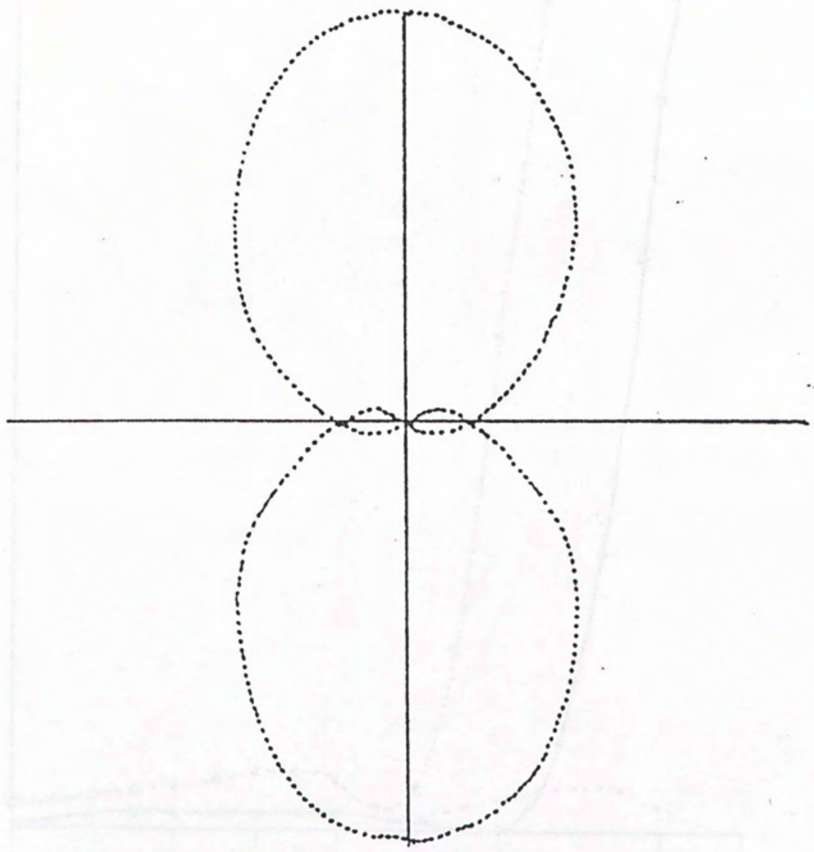
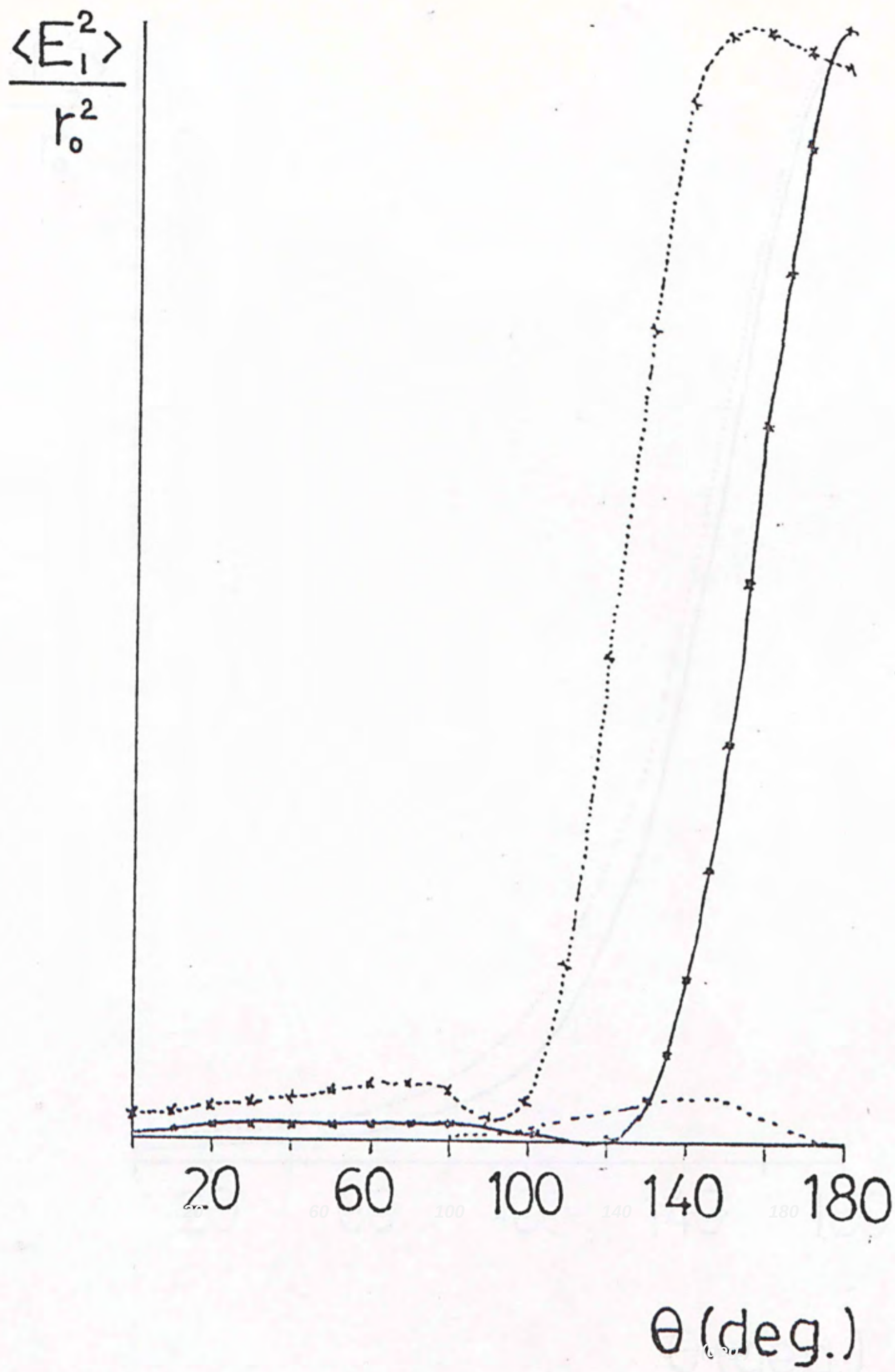


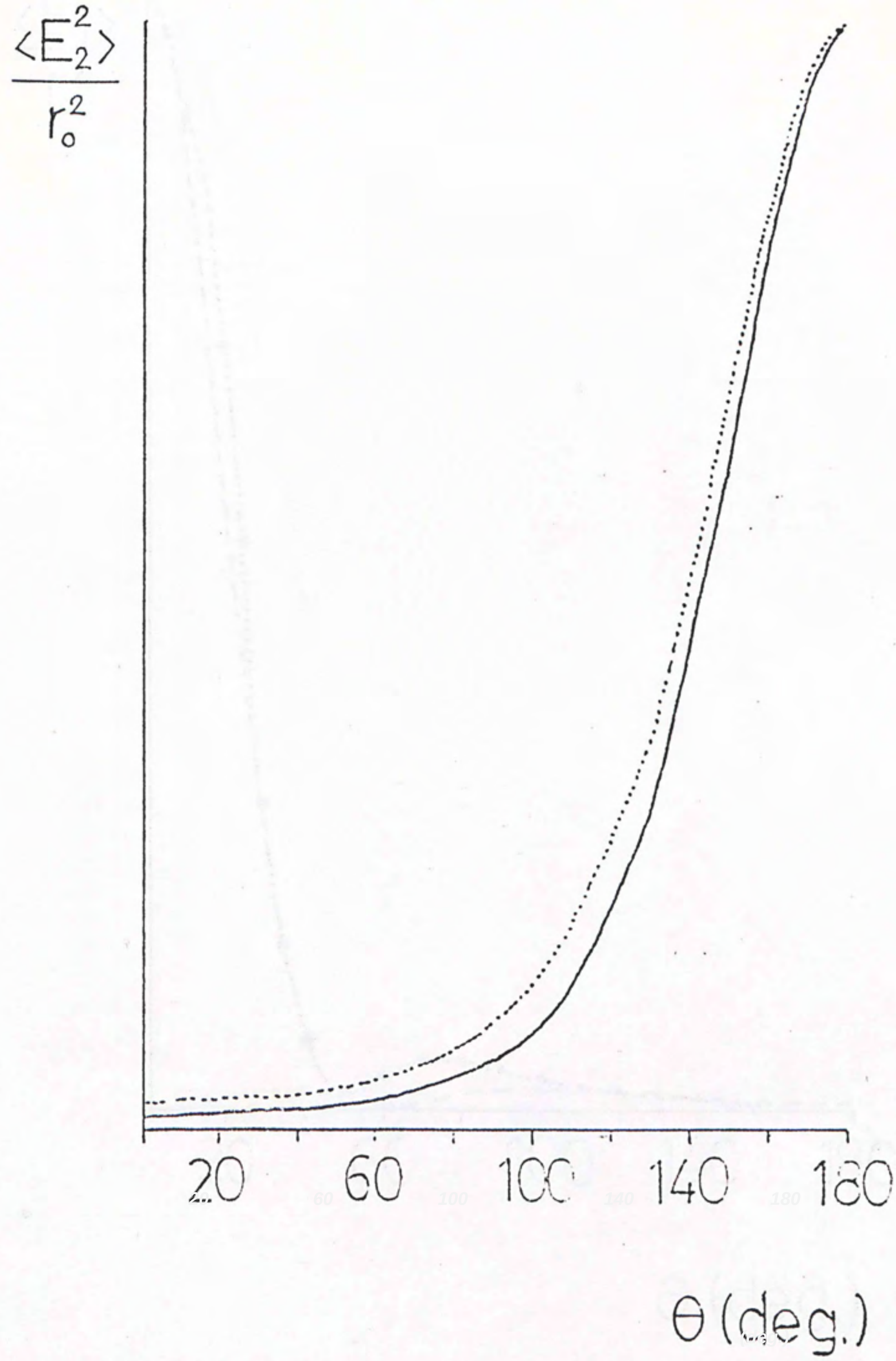
Figure 4-4(c) $\beta_0=-0.5$ $\overline{\Delta\epsilon}_K=1$ $\theta=90^\circ$ $\phi=90^\circ$



—x—x—x— $\overline{\Delta\epsilon}_K=0.01$ $\phi=0°$

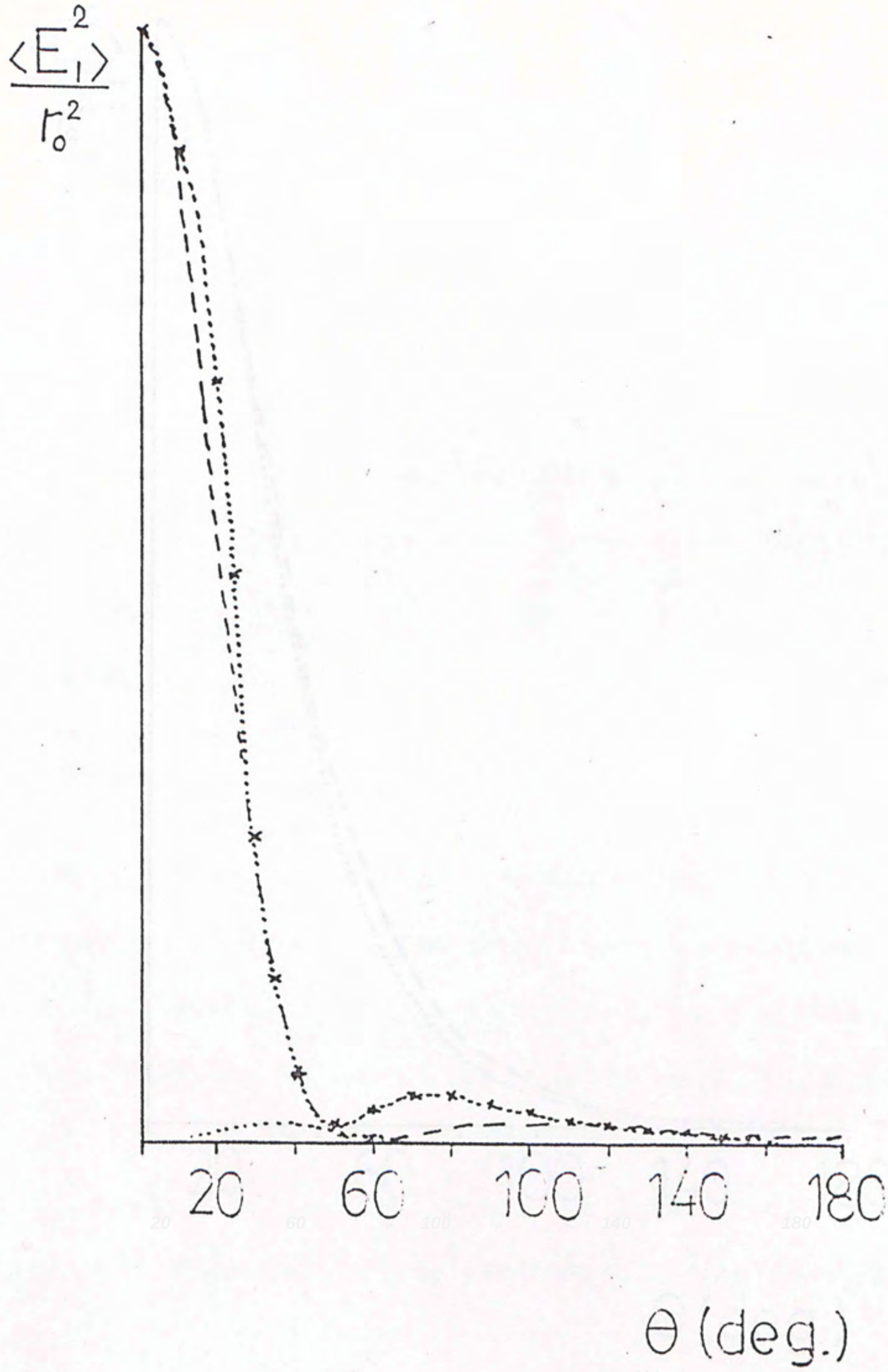
---x--x--x-- $\overline{\Delta\epsilon}_K=0.1$ $\phi=0°$ --------- $\overline{\Delta\epsilon}_K=0.1$ $\phi=90°$

Figure 4-5



——— $\overline{\Delta\epsilon}_K$=0.01 ϕ=90° ········· $\overline{\Delta\epsilon}_K$=0.1 ϕ=90°

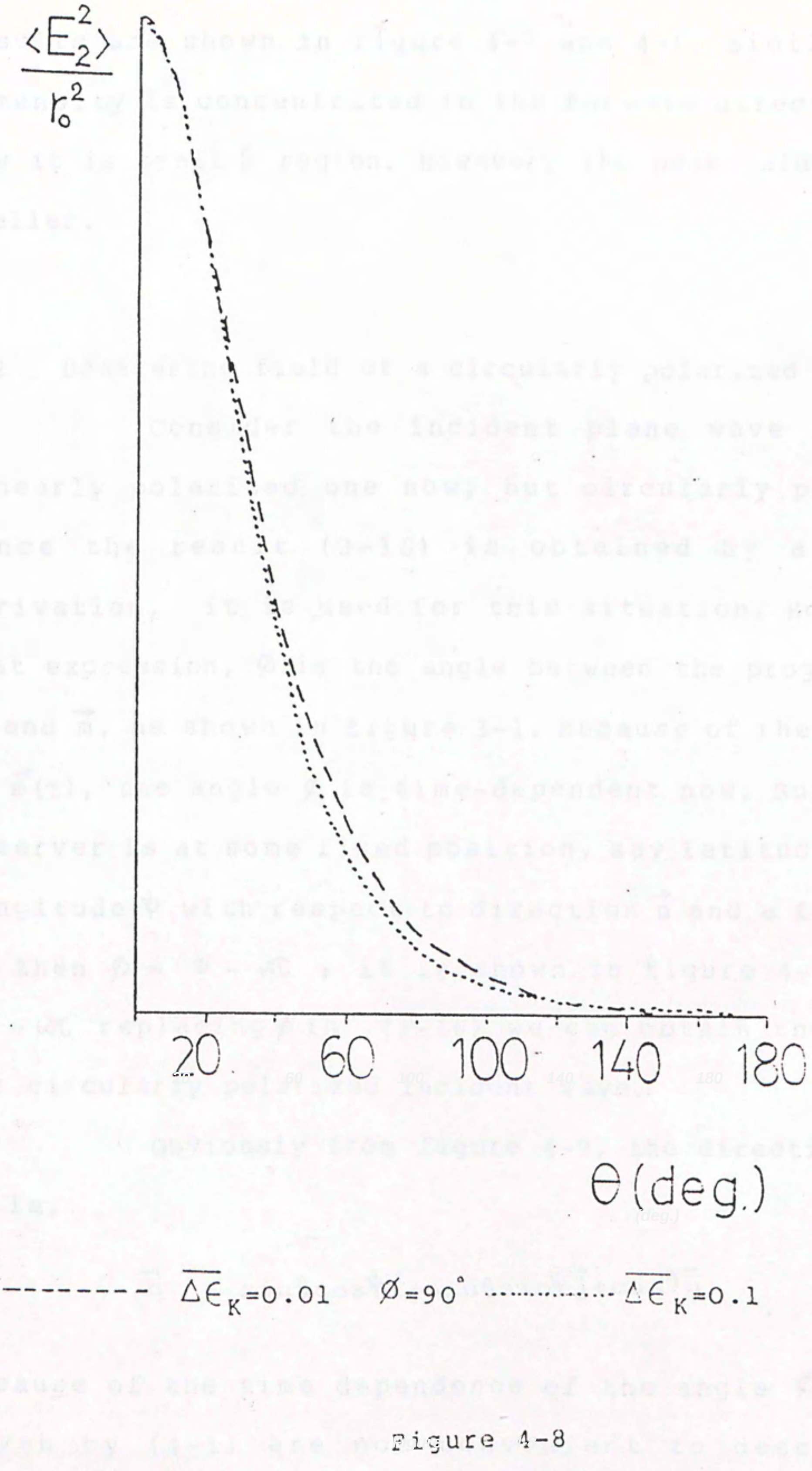
Figure 4-6



-------- $\overline{\Delta\epsilon}_K = 0.01$ $\phi = 0°$

···x···x···x··· $\overline{\Delta\epsilon}_K = 0.1$ $\phi = 0°$ .... $\overline{\Delta\epsilon}_K = 0.1$ $\phi = 90°$

Figure 4-7



------- $\overline{\Delta\epsilon}_K = 0.01$ $\phi = 90^\circ$ .... $\overline{\Delta\epsilon}_K = 0.1$ $\phi = 90^\circ$

Figure 4-8

electron travels with same direction as $\vec{n}$, say $\beta_0=0.5$, the results are shown in figure 4-7 and 4-8. Similarly the intensity is concentrated in the forward direction, but now it is small θ region. However, the peak value is much smaller.

4.2 Scattering field of a circularly polarized plane wave

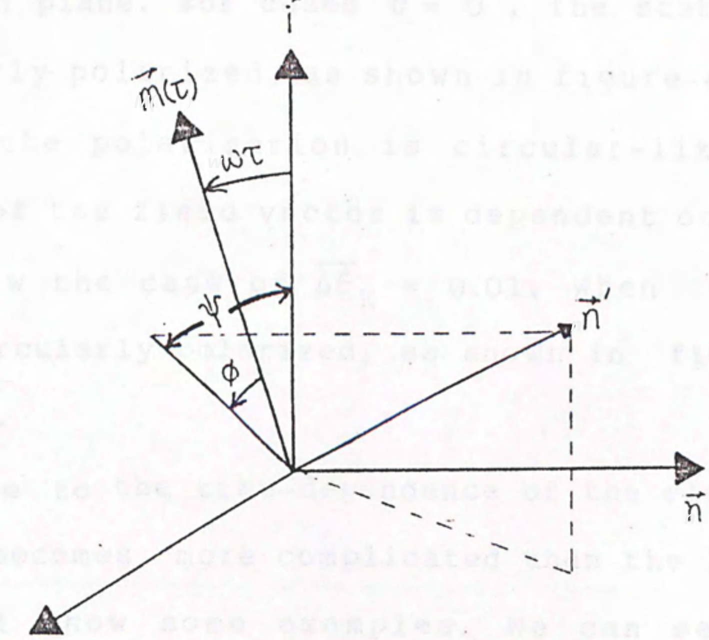
Consider the incident plane wave is not a linearly polarized one now, but circularly polarized. Since the result (3-16) is obtained by a general derivation, it is used for this situation. However in that expression, ϕ is the angle between the projection of $\vec{n}'$ and $\vec{m}$, as shown in figure 3-1. Because of the rotation of $\vec{m}(\tau)$, the angle ϕ is time-dependent now. Suppose the observer is at some fixed position, say latitude θ and longitude ψ with respect to direction $\vec{n}$ and a fixed axis $\vec{i}$, then $\phi = \psi - \omega\tau$; it is shown in figure 4-9. To use $\psi - \omega\tau$ replacing ϕ in (3-16) we can obtain the results for circularly polarized incident wave.

Obviously from figure 4-9, the direction vector $\vec{n}'$ is,

$$\vec{n}' = \sin\theta\cos\psi\vec{i}+\sin\theta\sin\psi\vec{j}+\cos\theta\vec{n} \qquad (4-3)$$

Because of the time dependence of the angle ϕ, $\vec{\varepsilon}_1$, $\vec{\varepsilon}_2$ given by (4-1) are not convenient to describe the scattering electric field vector. After simple substitution $\phi = \psi - \omega\tau$, we can obtain a set of time-

Fig. 4-9



vectors,

$$\vec{\varepsilon}_1 = \cos\theta\cos\psi\vec{i}+\cos\theta\sin\psi\vec{j}-\sin\theta\vec{n} \tag{4-4a}$$

$$\vec{\varepsilon}_2 = -\sin\psi\vec{i}+\cos\psi\vec{j}\,. \tag{4-4b}$$

As a particular example, first consider the case that the electron is at rest initially. Directly from (3-16) by taking $\alpha = 1$ and $\phi = \psi - \omega\tau$, scattering electric field vector $\vec{E}_r$ can be calculated. By the same treatment of the previous section. We can plot the locus of the movement of the electric field vector on each polarization plane. For cases $\theta = 0^\circ$, the scattering wave is circularly polarized, as shown in figure 4-10(c). For $\theta = 180^\circ$, the polarization is circular-like, but the magnitude of the field vector is dependent on τ, figure 4-10(d) show the case of $\overline{\Delta\epsilon}_K = 0.01$. When $_K$ is zero, both are circularly polarized, as shown in figure 4-10(a) and 4-10(b).

Due to the time-dependence of the electric field vector, it becomes more complicated than the linear case, figure 4-11 show some examples. We can see that the movement of the field vector on the polarization plane is very confused. However when $\overline{\Delta\epsilon}_K$ becomes smaller, the field behaves like linearly polarized.

Similarly, figure 4-12 and 4-13 show the intensity along each polarization direction $\vec{\varepsilon}_1$ and $\vec{\varepsilon}_2$ against θ, for (a) $\psi = 0^\circ$, (b) $\psi = 90^\circ$ and $\overline{\Delta\epsilon}_K = 0.01$, 0.1 and 1.

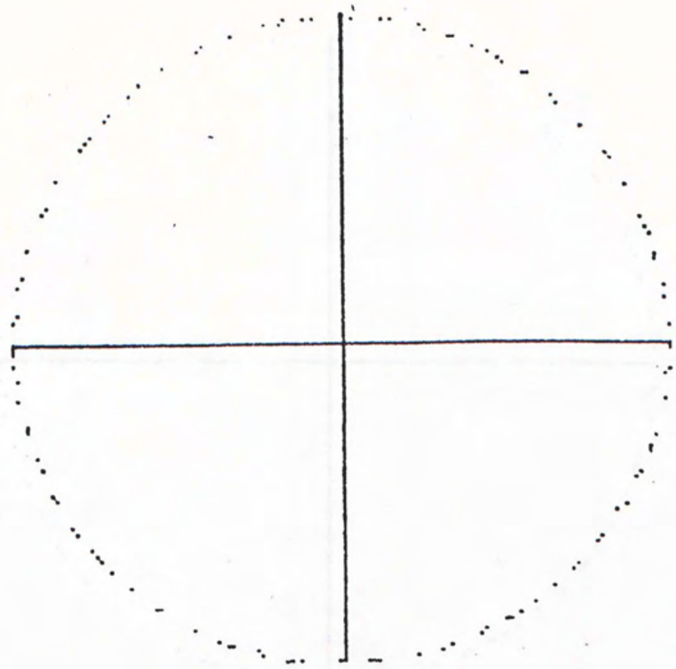


Figure 4-10(a) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0$ $\theta=0^\circ$ $\psi=0^\circ$

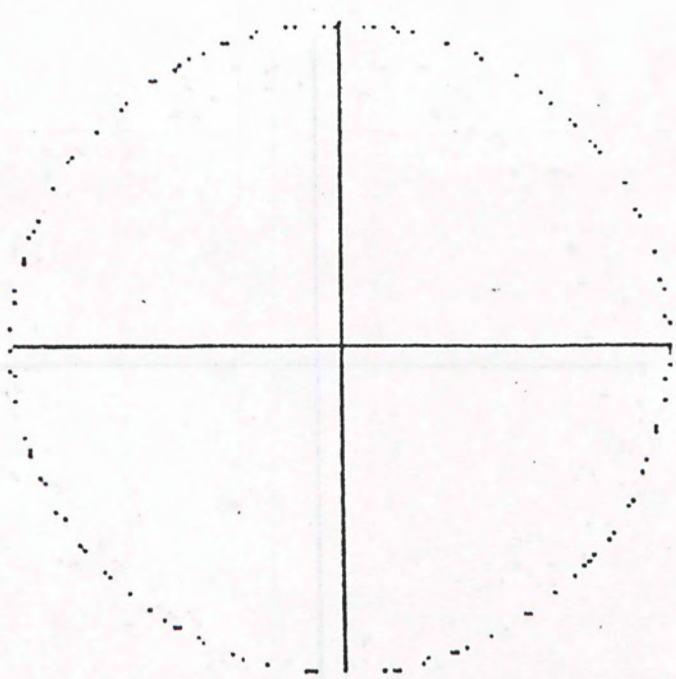


Figure 4-10(b) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0$ $\theta=180^\circ$ $\psi=0^\circ$

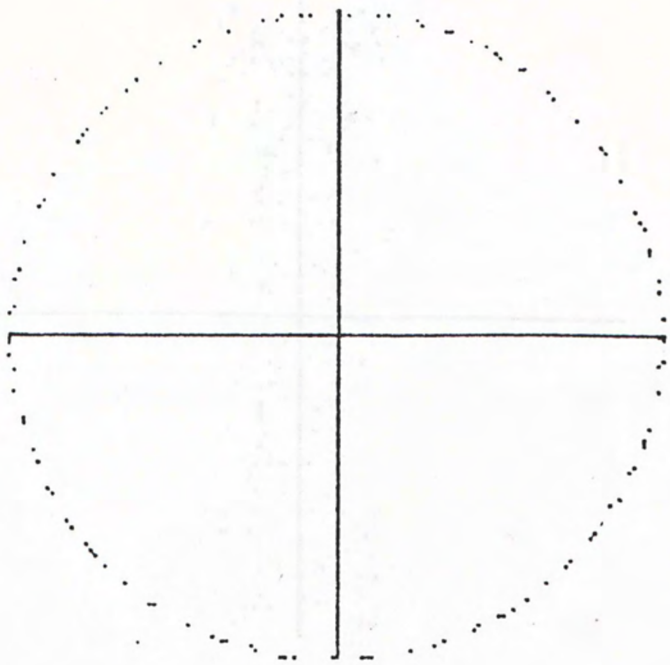


Figure 4-10(c) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.01$ $\theta=0°$ $\psi=0°$

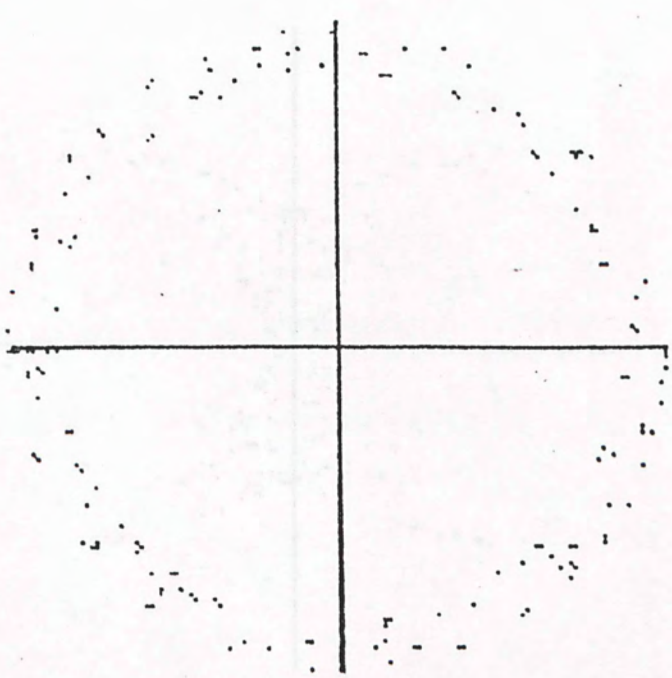


Figure 4-10(d) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.01$ $\theta=180°$ $\psi=0°$

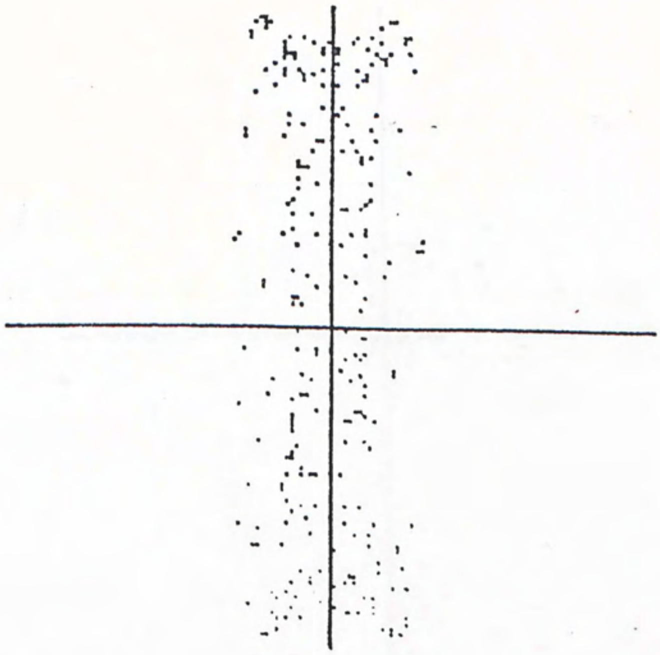


Figure 4-11(a) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.01$ $\theta=90°$ $\psi=90°$

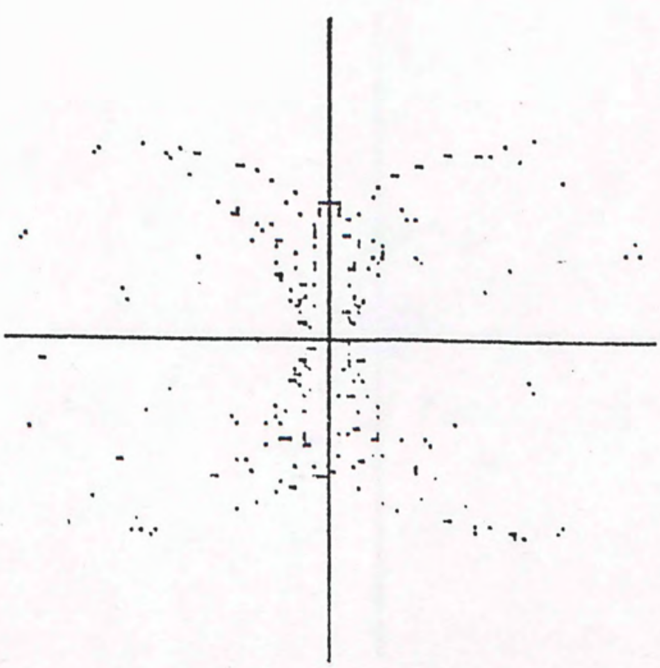
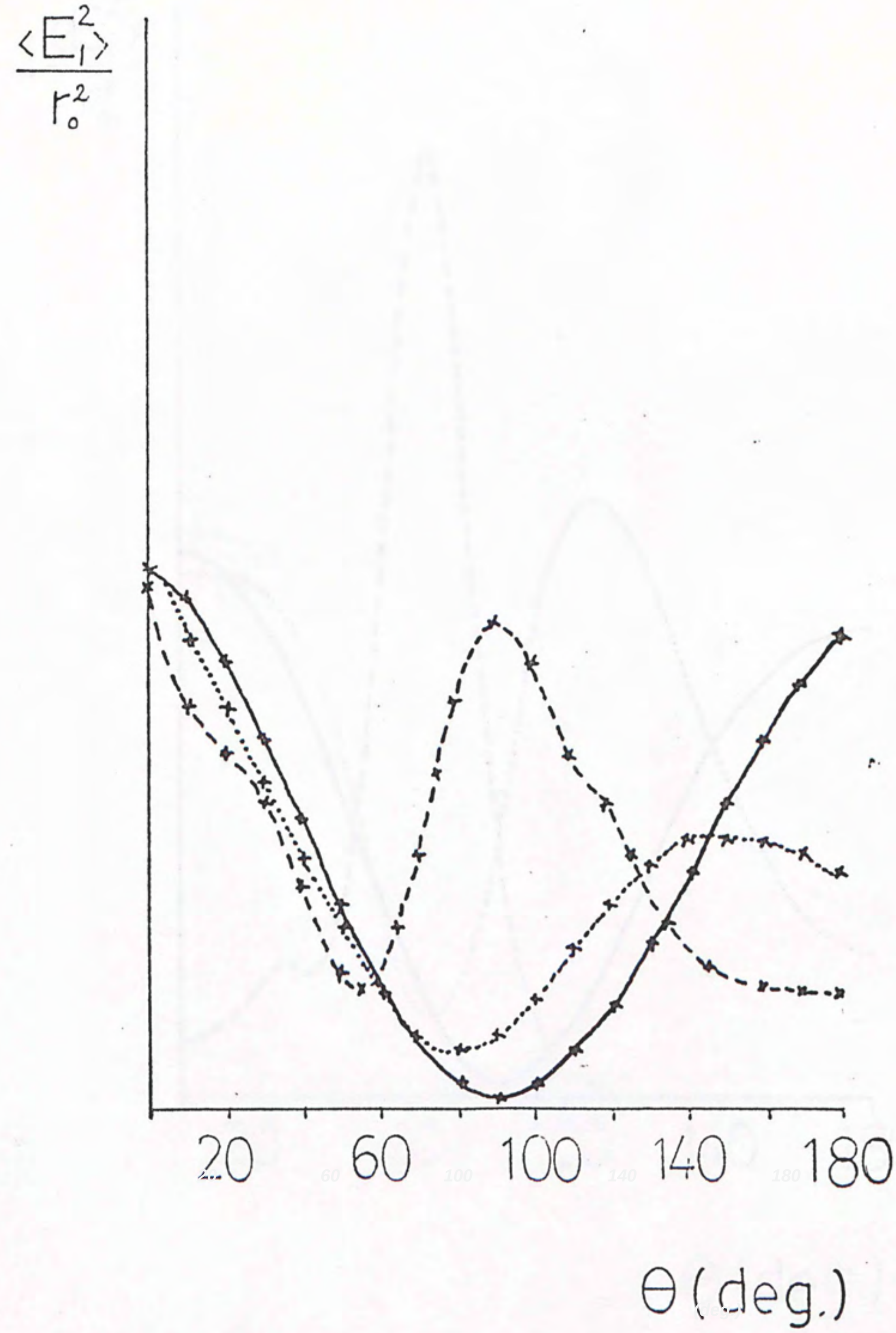


Figure 4-11(b) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.1$ $\theta=90°$ $\psi=90°$

Figure 4-11(c) $\beta_o=0$ $\overline{\Delta\epsilon}_K=0.5$ $\theta=90^\circ$ $\psi=90^\circ$

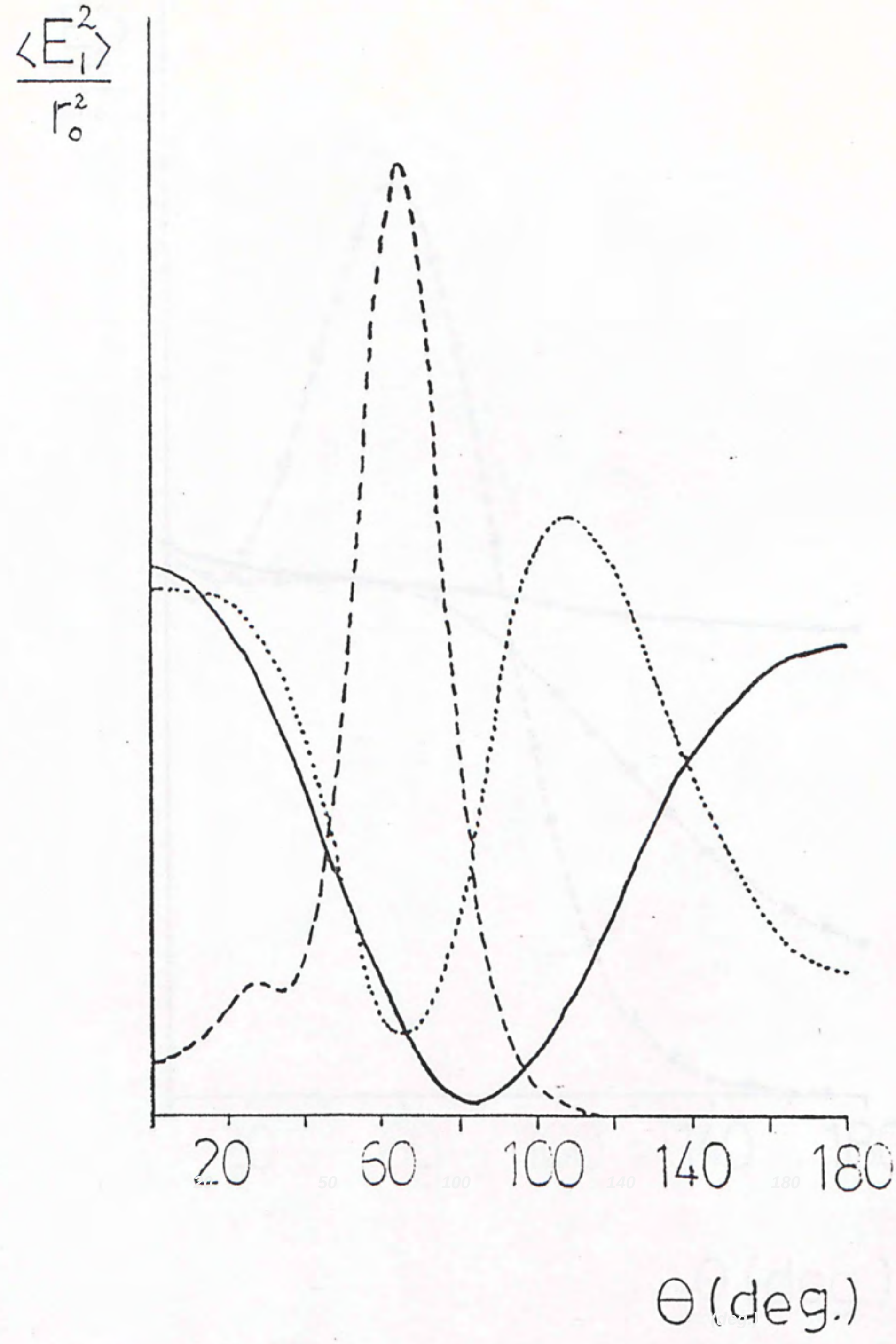
Figure 4-11(d) $\beta_o=0$ $\overline{\Delta\epsilon}_K=1$ $\theta=90^\circ$ $\psi=90^\circ$



—x—x—x— $\overline{\Delta\epsilon}_K=0.01$ ···x··x··x·· $\overline{\Delta\epsilon}_K=0.1$

–x–x–x–– $\overline{\Delta\epsilon}_K=1$ ($\psi = 0^\circ$)

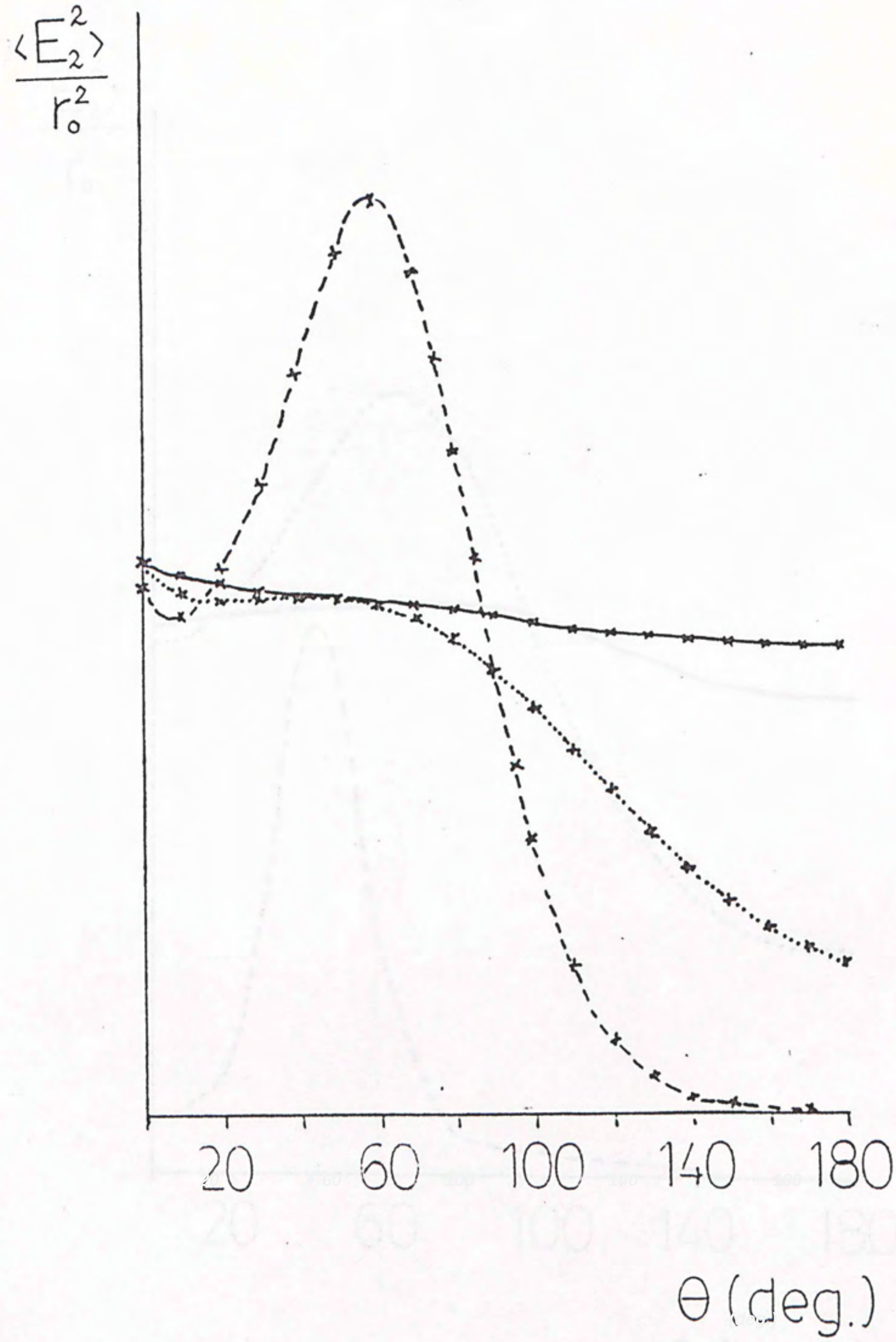
Figure 4-12(a)



—— $\overline{\Delta\epsilon}_K = 0.01$ .... $\overline{\Delta\epsilon}_K = 0.1$

- - - - - $\overline{\Delta\epsilon}_K = 1$ (ψ = 90°)

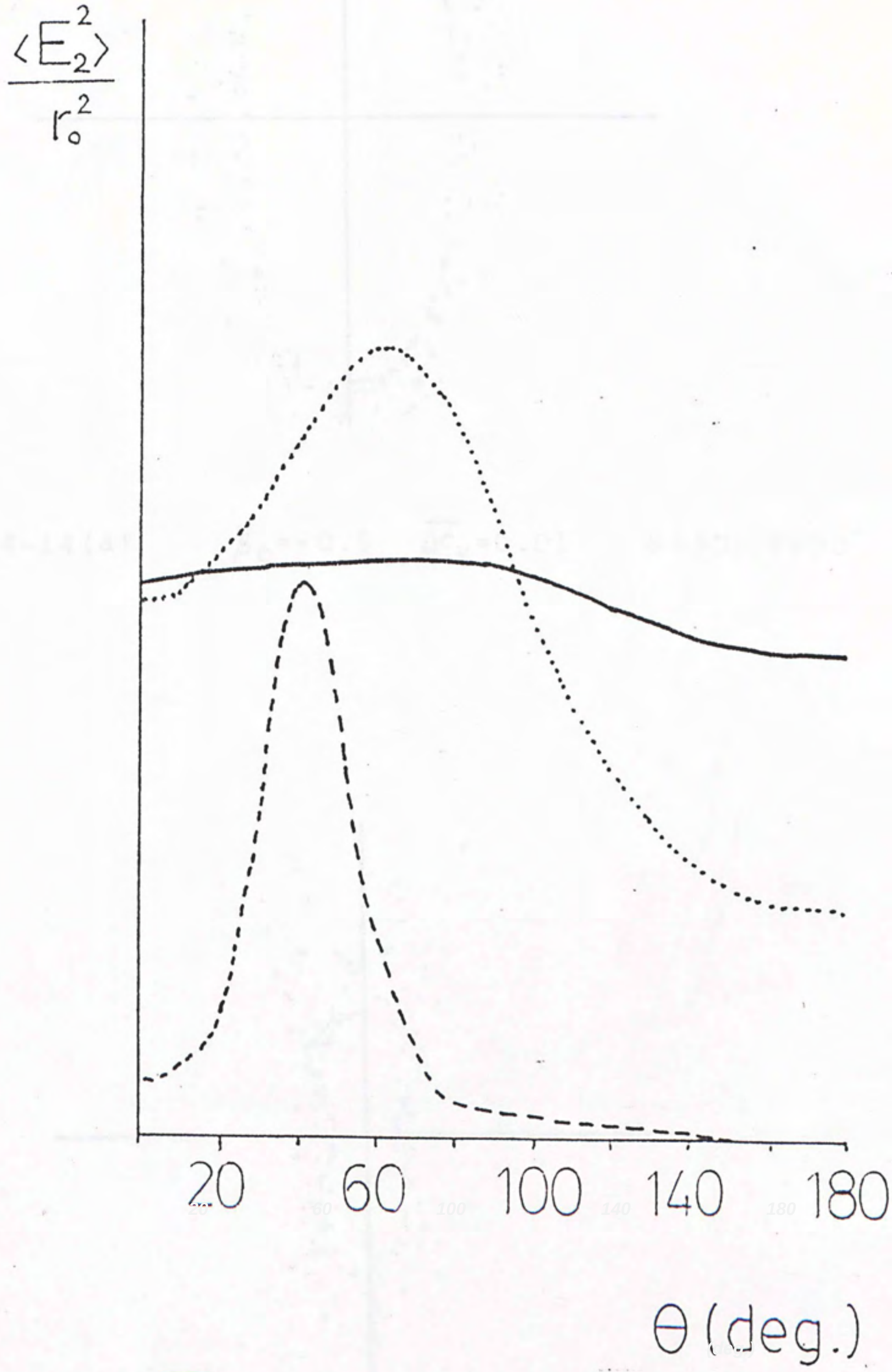
Figure 4-12(b)



—x—x—x— $\overline{\Delta\epsilon}_K$=0.01 ···x···x···x··· $\overline{\Delta\epsilon}_K$=0.1

-x-x-x- $\overline{\Delta\epsilon}_K$=1 (ψ = 0°)

Figure 4-13(a)



——— $\overline{\Delta\epsilon}_K$=0.01 .... $\overline{\Delta\epsilon}_K$=0.1

------ $\overline{\Delta\epsilon}_K$=1 (ϕ = 90°)

Figure 4-13(b)

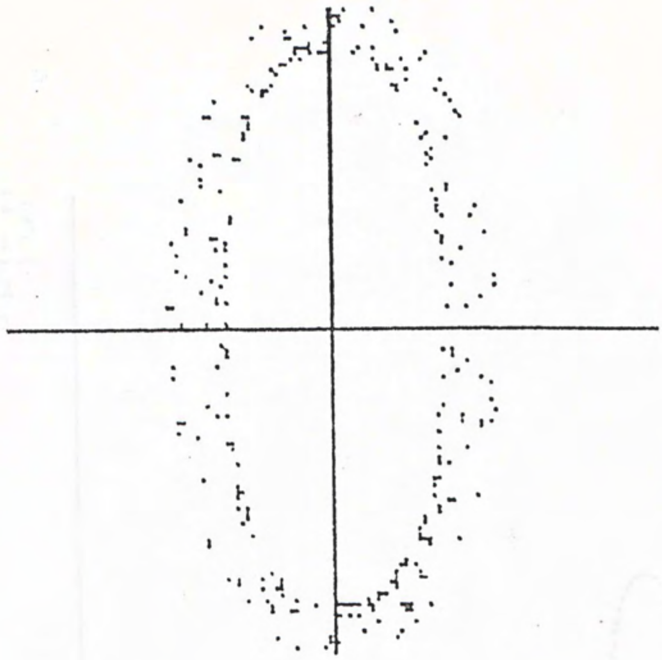


Figure 4-14(a) β_o=-0.5 $\overline{\Delta\epsilon}_K$=0.01 θ=90 ψ=90°

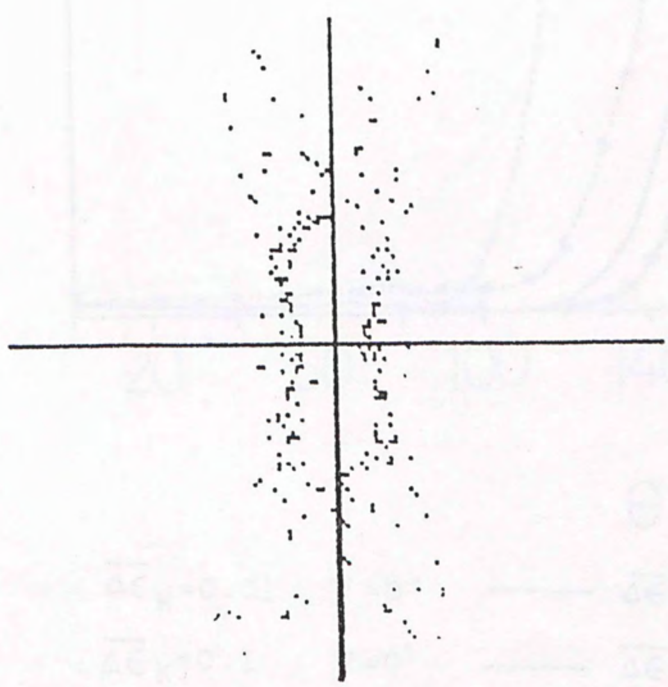


Figure 4-14(b) β_o=-0.5 $\overline{\Delta\epsilon}_K$=0.1 θ=90 ψ=90°

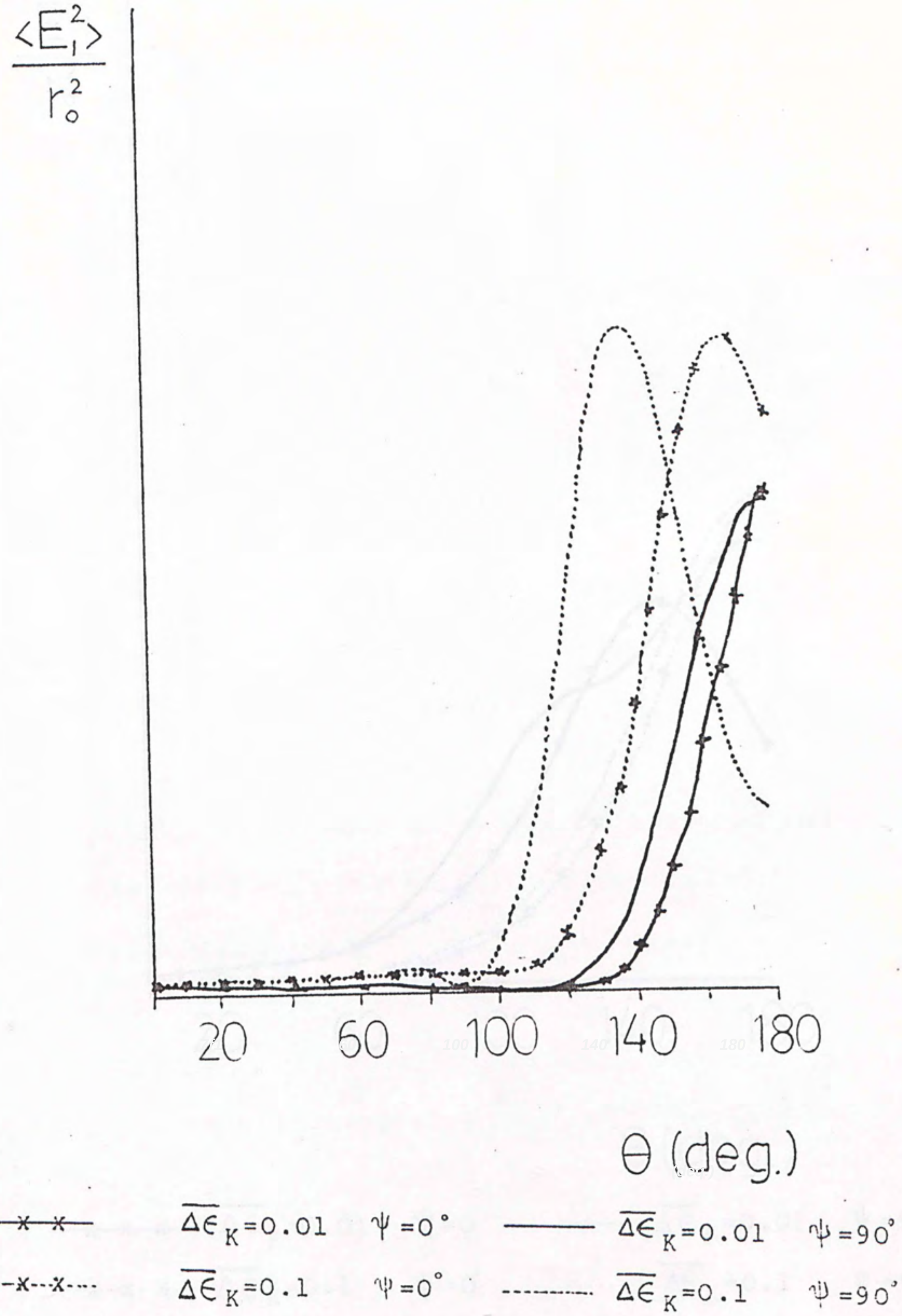
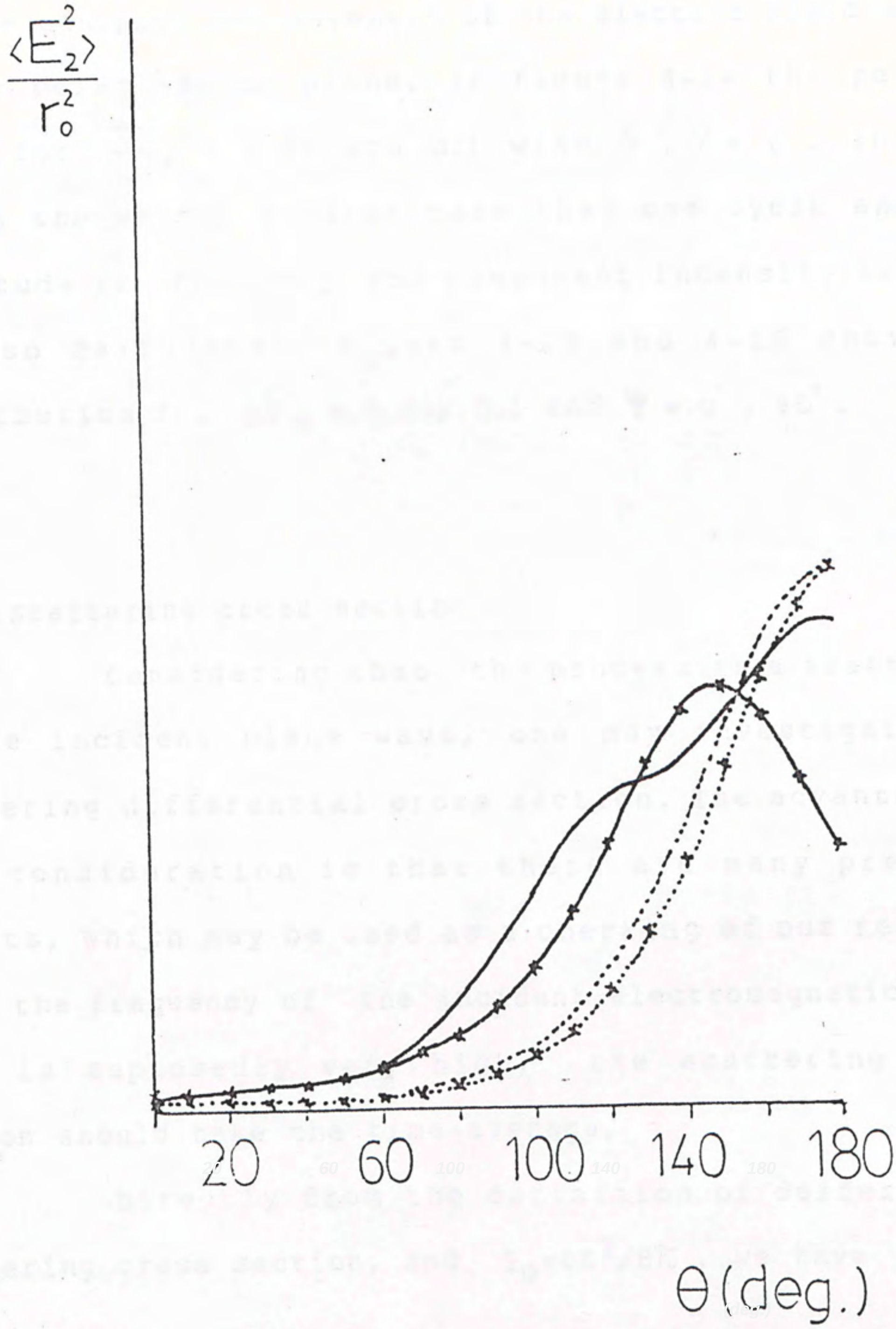

$\frac{\langle E_1^2 \rangle}{r_o^2}$
20
60
100
140
180
Θ (deg.)
$\overline{\Delta\epsilon}_K$=0.01 ψ=0°
$\overline{\Delta\epsilon}_K$=0.01 ψ=90°
$\overline{\Delta\epsilon}_K$=0.1 ψ=0°
$\overline{\Delta\epsilon}_K$=0.1 ψ=90°

Figure 4-15



—x—x—x— $\overline{\Delta\epsilon}_K=0.01$ $\psi=0^\circ$ ——— $\overline{\Delta\epsilon}_K=0.01$ $\psi=90^\circ$

---x--x--x--- $\overline{\Delta\epsilon}_K=0.1$ $\psi=0^\circ$ .... $\overline{\Delta\epsilon}_K=0.1$ $\psi=90^\circ$

Figure 4-16

Suppose the electron has an initial velocity of half of speed of light and travels towards the plane wave, then we can plot the movement of the electric field vector on the polarization plane. In figure 4-14 the pattern shown for $\overline{\Delta\epsilon}_K = 0.01$ and 0.1 with θ, $\psi = 0^\circ$. In one period the vector rotates more than one cycle and its magnitude is changing. The component intensity against θ is also calculated. Figure 4-15 and 4-16 show the distribution for $\overline{\Delta\epsilon}_K = 0.01$, 0.1 and $\psi = 0^\circ, 90^\circ$.

4.3 Scattering cross section

Considering that the process is a scattering of the incident plane wave, one may investigate the scattering differential cross section. The advantage of this consideration is that there are many previous results, which may be used as a checking of our results. Since the frequency of the incident electromagnetic plane wave is supposedly very high, the scattering cross section should take the time-average.

Directly from the definition of defferential scattering cross section, and $I_0 = cE^2/8\pi$, we have

$$\overline{\frac{d\sigma}{d\Omega}} = \overline{\left(\frac{E_r(\tau)}{E(\tau)}\right)^2} \qquad (4\text{-}5)$$

Substituting into (3-16),

$$\frac{d\sigma}{d\Omega} = r_0^2\left(\frac{\delta'}{\delta}\right)^4\left[(M\cos\phi\cos\theta - N\sin\theta)^2 + (M\sin\phi)^2\right] \; . \qquad (4\text{-}6)$$

Because of the different time-dependence of the scattering field, both the linearly and circularly incident wave are considered. Figure 4-17 and 4-18 are the results for an electron at rest initially. Figure 4-19 and 4-20 are that for an electron travelling with velocity half of speed of light (a) towards or (b) parallel to the incident wave initially. All the graphs are normalized such that the maxima are one.

Since the process is relativistic, so the electron travelling towards the wave should radiate more energy. Comparing both cases (a) and (b) of the figures, one may see that (a) is more significant. As shown in the table 4-1, one can find that the peak value for case (a) is much larger.

Chan and Lee have claimed that for linearly incident wave, the classical formula of the differential scattering cross section is similar to the Klein-Nishina formula(4),

$$\frac{d\sigma_{K-N}}{d\Omega} = \frac{r_o^2}{2}\left(\frac{\nu'}{\nu}\right)^3\left(\frac{\nu'}{\nu}+\frac{\nu}{\nu'}-2\sin^2\phi\cos^2\theta\right) \qquad (4\text{-}7)$$

where ν'/ν are the frequency ratio of the Compton scattering,

$$\frac{\nu'}{\nu} = \frac{1}{1+\alpha(1-\cos\theta)} \qquad (4\text{-}8)$$

with $\alpha = h\nu/mc^2$ the normalized kinetic energy of the incident photon and it is equal to $\overline{\Delta\epsilon}_K$.

		Polarization of the incident E.M. plane wave	Linear		Circular	
		Direction of initial vel.	$\vec{\beta}_0 \uparrow\downarrow \vec{n}$	$\vec{\beta}_0 \uparrow\uparrow \vec{n}$	$\vec{\beta}_0 \uparrow\downarrow \vec{n}$	$\vec{\beta}_0 \uparrow\uparrow \vec{n}$
Longitude of the observed position	0°	$\overline{\Delta\epsilon}_K = 0.01$	560	1	560	1
		$\overline{\Delta\epsilon}_K = 0.1$	470	1	230	1
	90°	$\overline{\Delta\epsilon}_K = 0.01$	560	1	560	1
		$\overline{\Delta\epsilon}_K = 0.1$	190	1	300	1

Table 4-1 Comparison of the maximun scattering cross section (The figures are relative to the smallest one.)

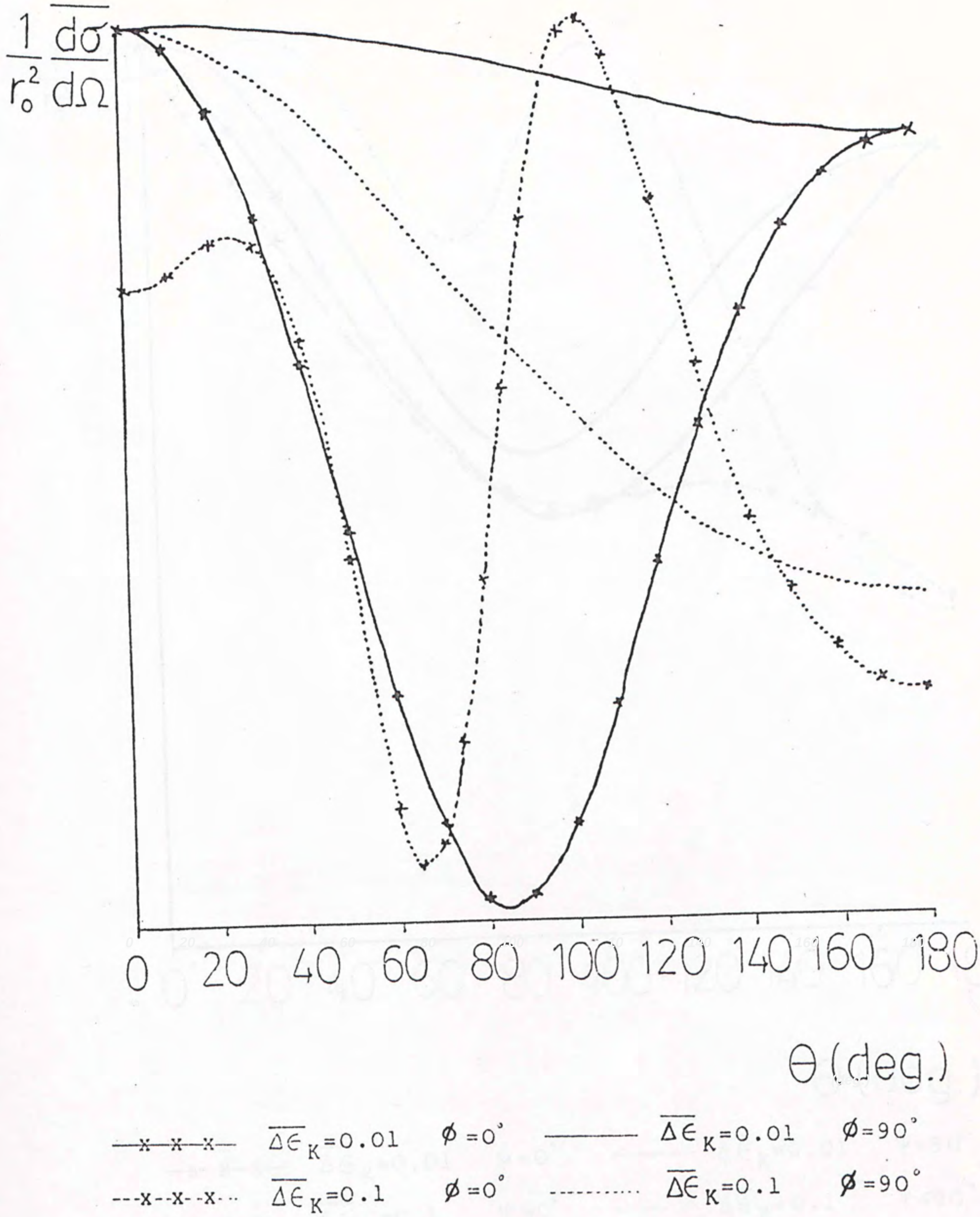
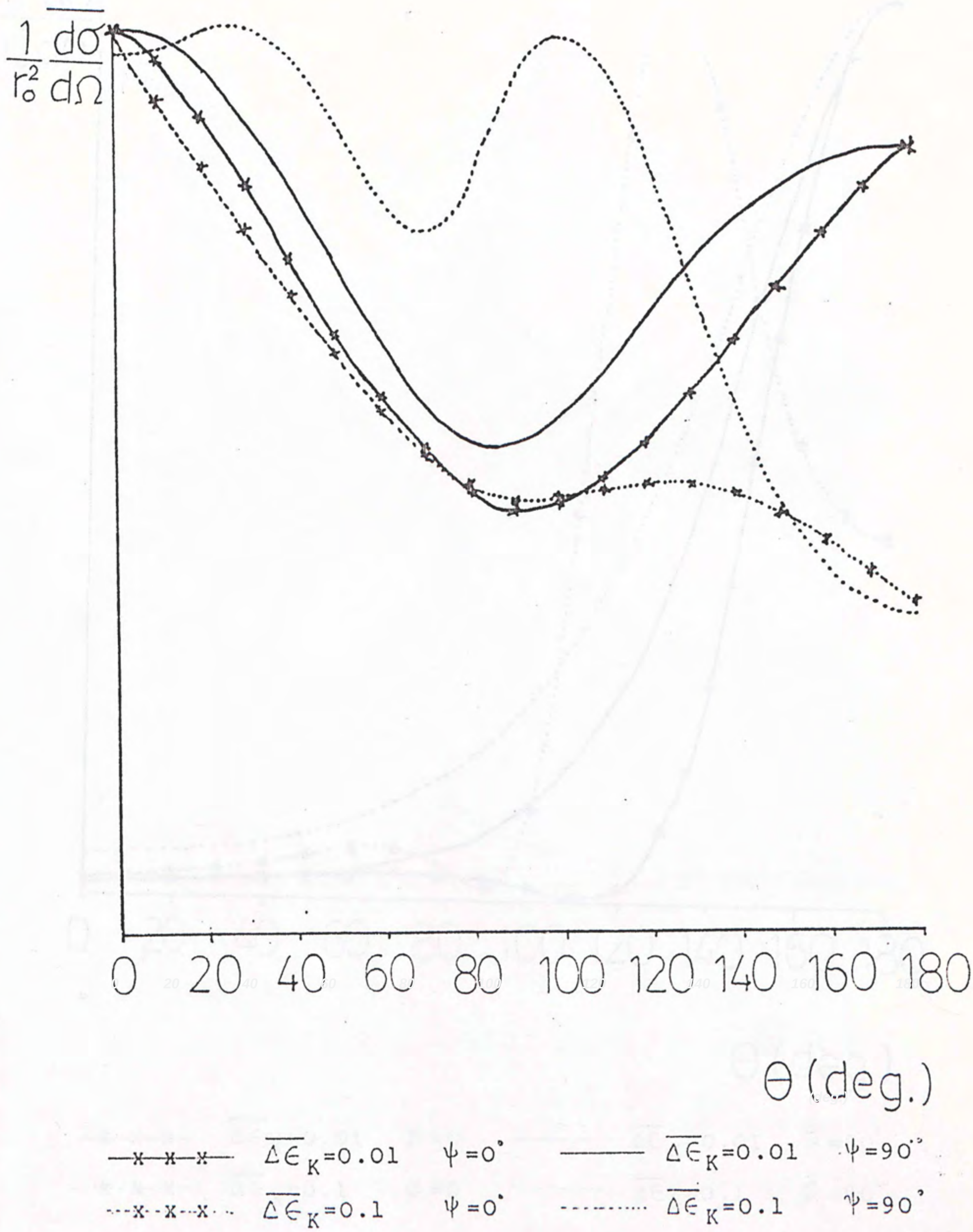
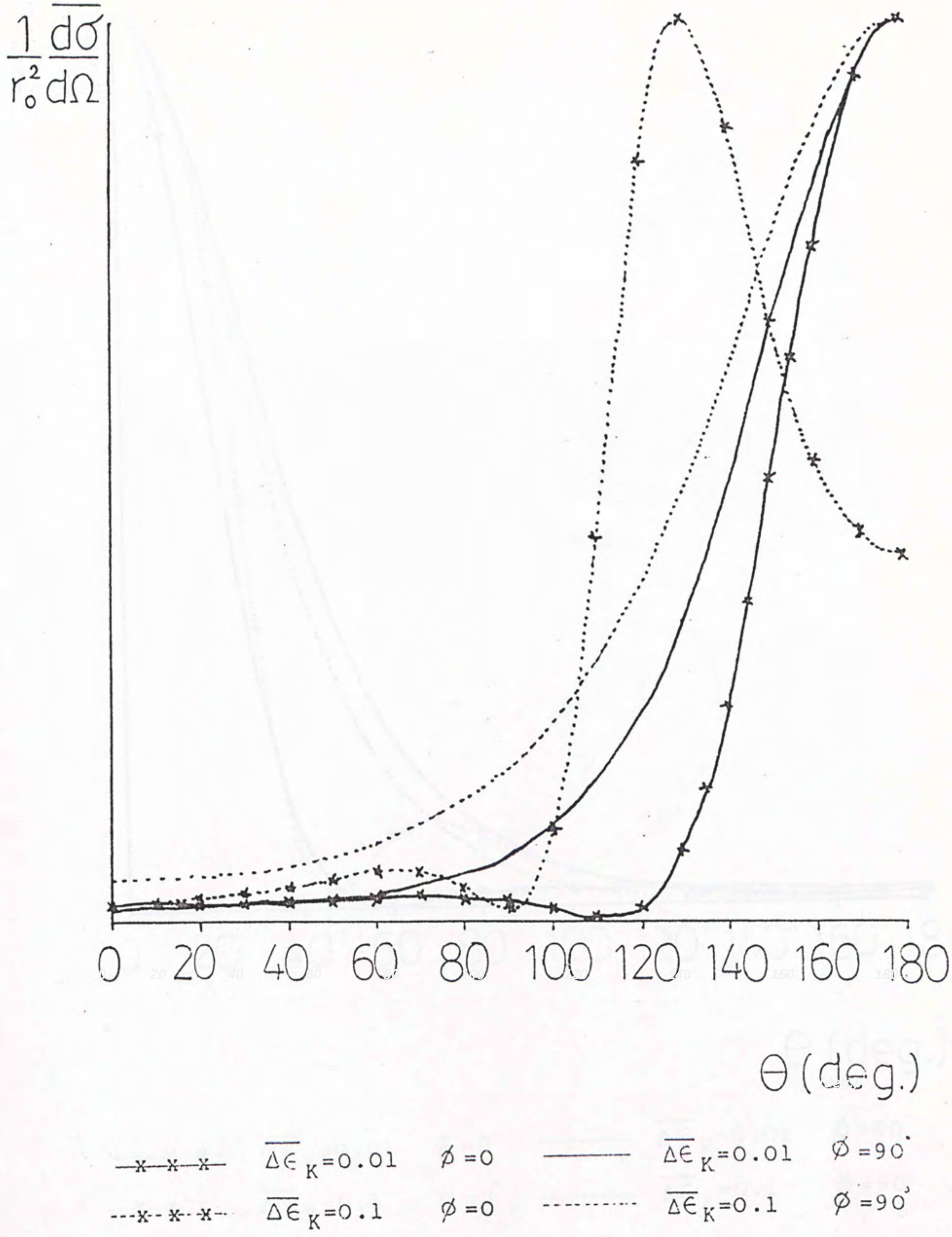

$\frac{1}{r_o^2}\overline{\frac{d\sigma}{d\Omega}}$
0 20 40 60 80 100 120 140 160 180
Θ(deg.)
—x—x—x— $\overline{\Delta\epsilon}_K$=0.01 ϕ=0°
———— $\overline{\Delta\epsilon}_K$=0.01 ϕ=90°
---x--x--x-- $\overline{\Delta\epsilon}_K$=0.1 ϕ=0°
.... $\overline{\Delta\epsilon}_K$=0.1 ϕ=90°

Figure 4-17



$\frac{1}{r_0^2}\frac{\overline{d\sigma}}{d\Omega}$
0 20 40 60 80 100 120 140 160 180
Θ (deg.)
—x—x—x— $\overline{\Delta\epsilon}_K=0.01$ $\psi=0°$
——— $\overline{\Delta\epsilon}_K=0.01$ $\psi=90°$
---x--x--x-- $\overline{\Delta\epsilon}_K=0.1$ $\psi=0°$
.... $\overline{\Delta\epsilon}_K=0.1$ $\psi=90°$

Figure 4-18



$\frac{1}{r_0^2}\overline{\frac{d\sigma}{d\Omega}}$
0 20 40 60 80 100 120 140 160 180
Θ (deg.)
$\overline{\Delta\epsilon}_K=0.01$ $\phi=0$
$\overline{\Delta\epsilon}_K=0.01$ $\phi=90°$
$\overline{\Delta\epsilon}_K=0.1$ $\phi=0$
$\overline{\Delta\epsilon}_K=0.1$ $\phi=90°$

Figure 4-19(a)

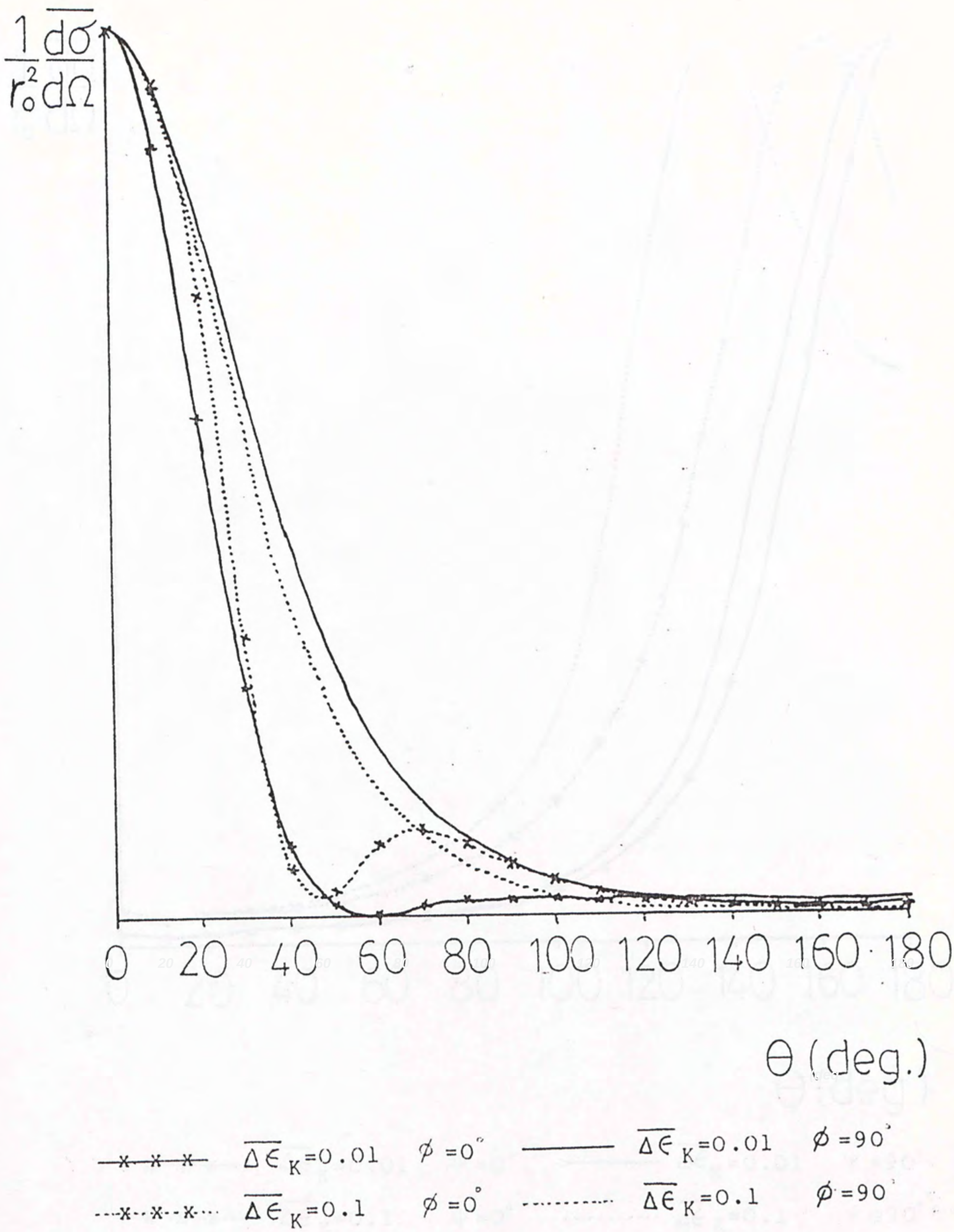

$\frac{1}{r_0^2}\frac{\overline{d\sigma}}{d\Omega}$
0 20 40 60 80 100 120 140 160 180
Θ (deg.)
$\overline{\Delta\epsilon}_K$=0.01 ϕ=0°
$\overline{\Delta\epsilon}_K$=0.01 ϕ=90°
$\overline{\Delta\epsilon}_K$=0.1 ϕ=0°
$\overline{\Delta\epsilon}_K$=0.1 ϕ=90°

Figure 4-19(b)

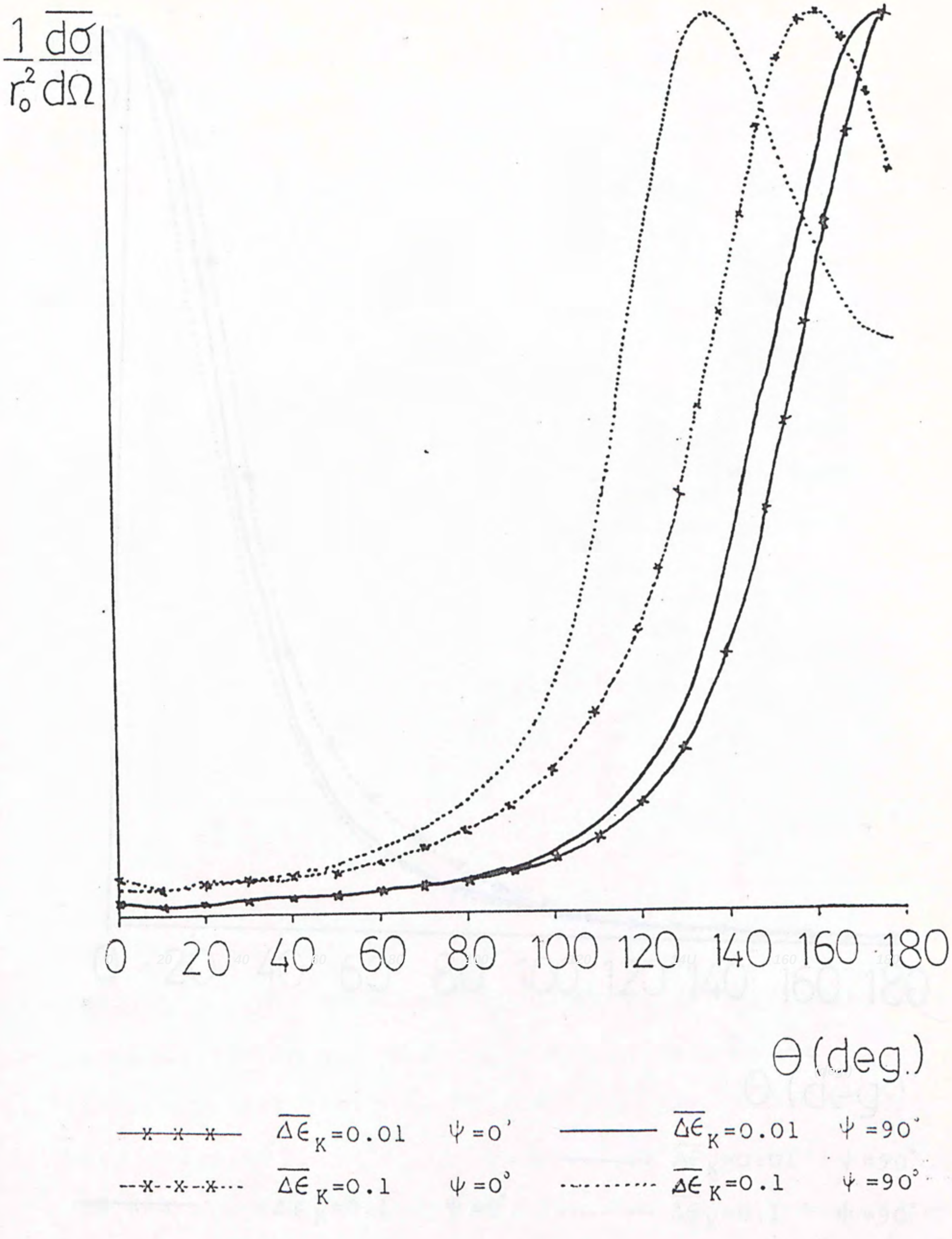

$\frac{1}{r_0^2}\overline{\frac{d\sigma}{d\Omega}}$
0 20 40 60 80 100 120 140 160 180
Θ (deg.)
$\overline{\Delta\epsilon}_K$=0.01 ψ=0°
$\overline{\Delta\epsilon}_K$=0.01 ψ=90°
$\overline{\Delta\epsilon}_K$=0.1 ψ=0°
$\overline{\Delta\epsilon}_K$=0.1 ψ=90°

Figure 4-20(a)

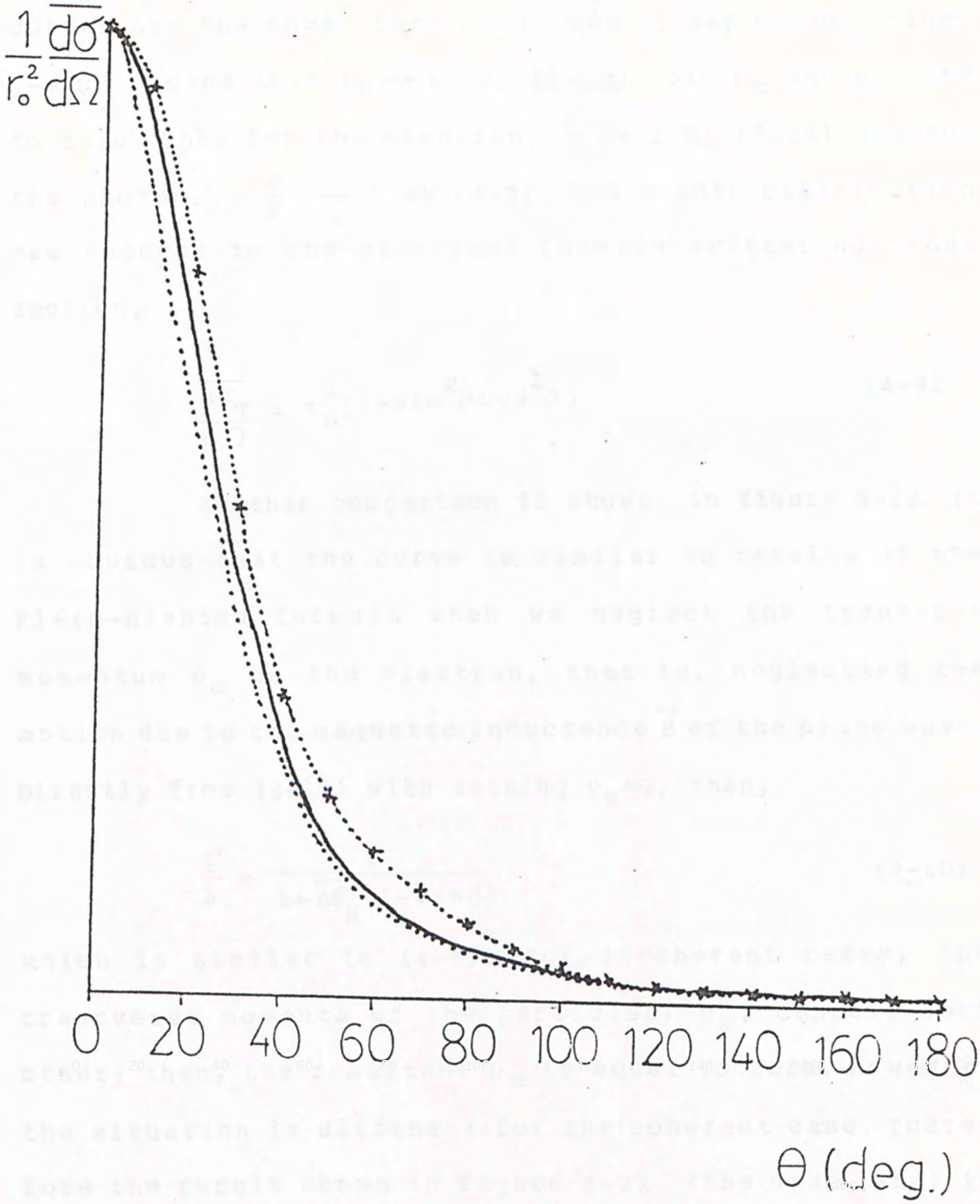

$\frac{1}{r_o^2}\overline{\frac{d\sigma}{d\Omega}}$
0 20 40 60 80 100 120 140 160 180
θ (deg.)
$\overline{\Delta\epsilon}_K$=0.01 ψ=90°
$\overline{\Delta\epsilon}_K$=0.1 ψ=0°
$\overline{\Delta\epsilon}_K$=0.1 ψ=90°

Figure 4-20(b)

Form the figure 4-21 we can see that the curves are the same for small $\overline{\Delta\epsilon}_K$, say 0.0001. Since $\overline{\Delta\epsilon}_K \rightarrow 0$ means that $E_0 \rightarrow 0$, by (2-12) both p_m and p_n tend to zero. Then for the electron, $\frac{\delta'}{\delta} \rightarrow 1$ by (3-14) and for the photon, $\frac{\nu'}{\nu} \rightarrow 1$ by (4-8). Hence both distribution are reduced to the classical Thomson scattering cross section,

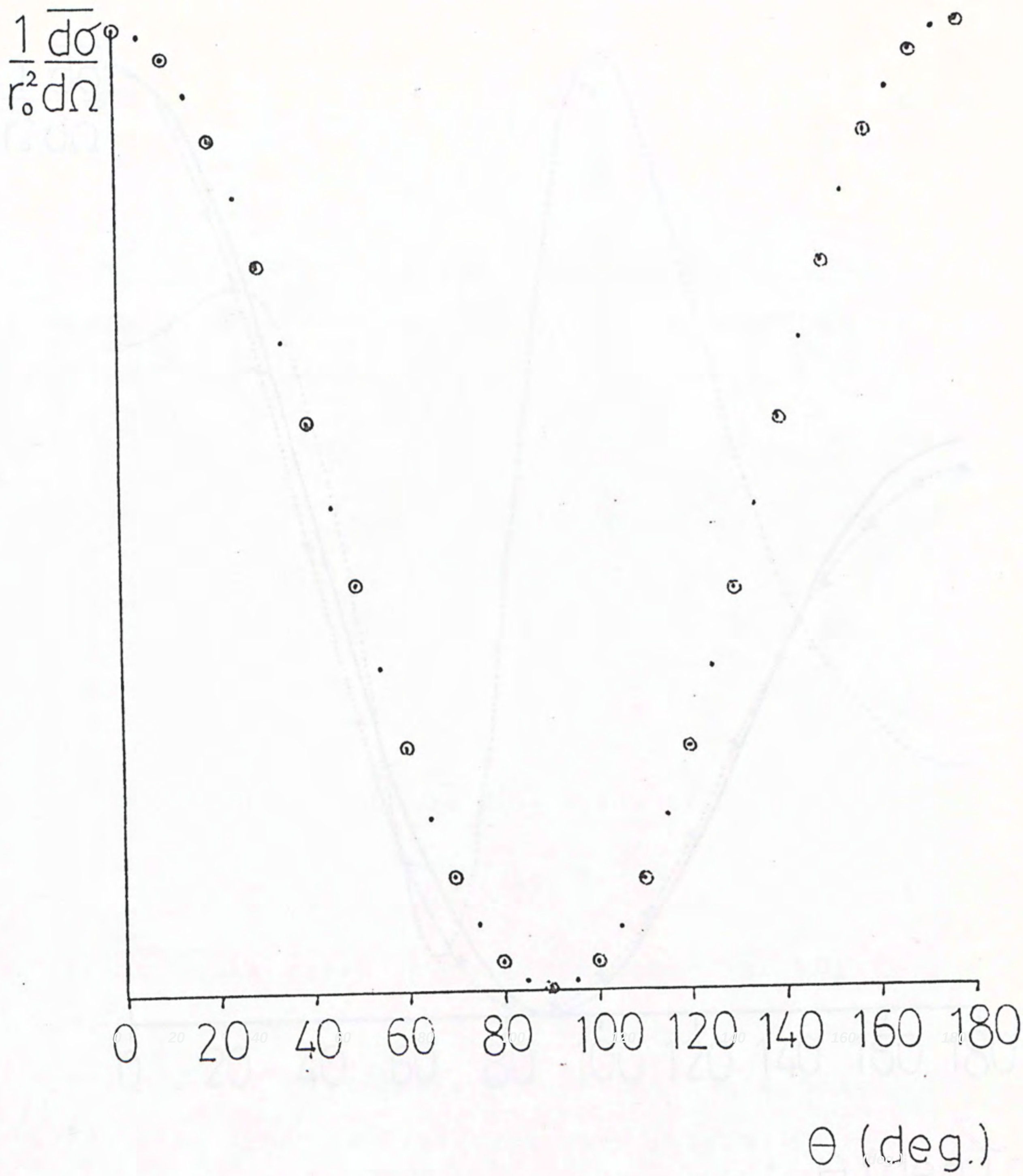
$$\frac{\overline{d\sigma_T}}{d\Omega} = r_0^2(1-\sin^2\theta\cos^2\phi) \tag{4-9}$$

Another comparison is shown in figure 4-22. It is obvious that the curve is similar to results of the Klein-Nishina formula when we neglect the transerve momentum p_m of the electron, that is, neglecting the motion due to the magnetic inductence $\vec{B}$ of the plane wave. Directly from (3-14) with setting $p_m=0$, then,

$$\frac{\delta'}{\delta} = \frac{1}{1+\overline{\Delta\epsilon}_K(1-\cos\theta)} \tag{4-10}$$

which is similar to (4-8). For incoherent cases, the transverse momenta of the particles, p_m, cancell each other; then, the resultant p_m is equal to zero. However, the situation is diffenent for the coherent case. Therefore the result shown in figure 4-22 (the dash line) is quite different. But p_n is the same for both cases. Moreover the electron has only p_n. Since the momentum of the electron equal to $\mathcal{E}/c$. Its motion is a wave-type motion, hence the quantum mechanical treatment is suitable.

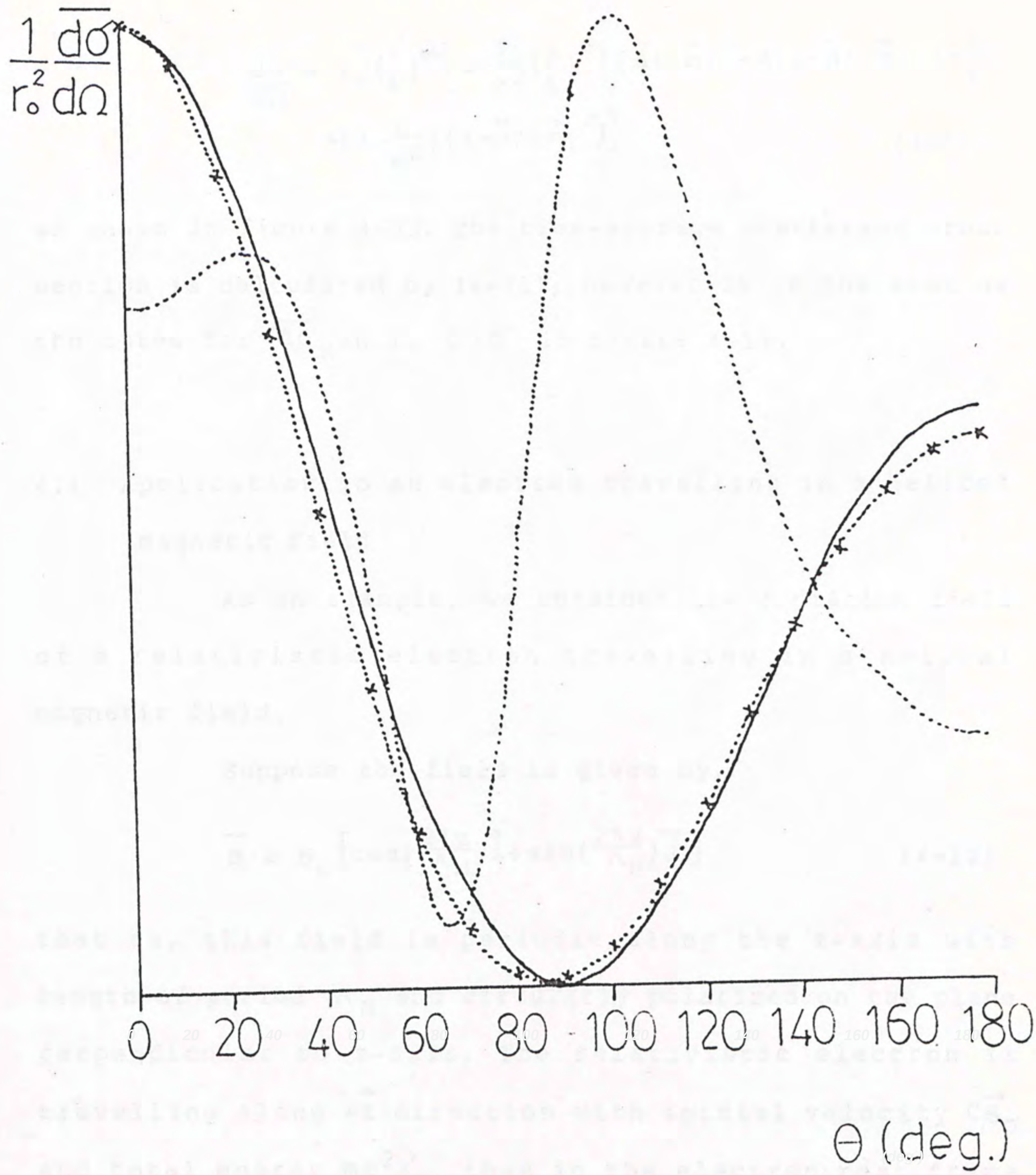
The result is also agreeable to the previous



...... By the formula (4-6) with $\overline{\Delta\epsilon}_K$=0.0001 (ϕ = 0°).

⊙ ⊙ ⊙ ⊙ Klein-Nishina formula with α=0.0001 (ϕ = 0°).

Figure 4-21



··········· By (4-6) with $\overline{\Delta\epsilon}_K=0.1$ ($\emptyset = 0^\circ$).

———— By (4-6), but p_m is set to zero ($\overline{\Delta\epsilon}_K=0.1$, $\emptyset=0^\circ$).

-×-×-× The Klein-Nishina formula with $\alpha=0.1$ ($\emptyset = 0^\circ$).

Figure 4-22

one by Chan[5],

$$\overline{\frac{d\sigma}{d\Omega}} = r_o^2\left(\frac{\delta'}{\delta}\right)^4\Big[1-\frac{1}{\alpha^2}\left(\frac{\delta'}{\delta}\right)^2\left((\vec{n}'\cdot\vec{m})^2-2(1-\vec{n}'\cdot\vec{n})\left(1-\frac{\delta}{\delta'}\right)\right.$$
$$\left.+\left(1-\frac{1}{\alpha^2}\right)(1-\vec{n}'\cdot\vec{n})^2\right)\Big] \tag{4-11}$$

as shown in figure 4-23. The time-average scattering cross section is calculated by (4-11); however it is the same as the curve for $\overline{\Delta\epsilon}_K=0.1$, $\phi=0°$ in figure 4-17.

4.4 Application to an electron travelling in a helical magnetic field

As an example, we consider the radiation field of a relativistic electron travelling in a helical magnetic field.

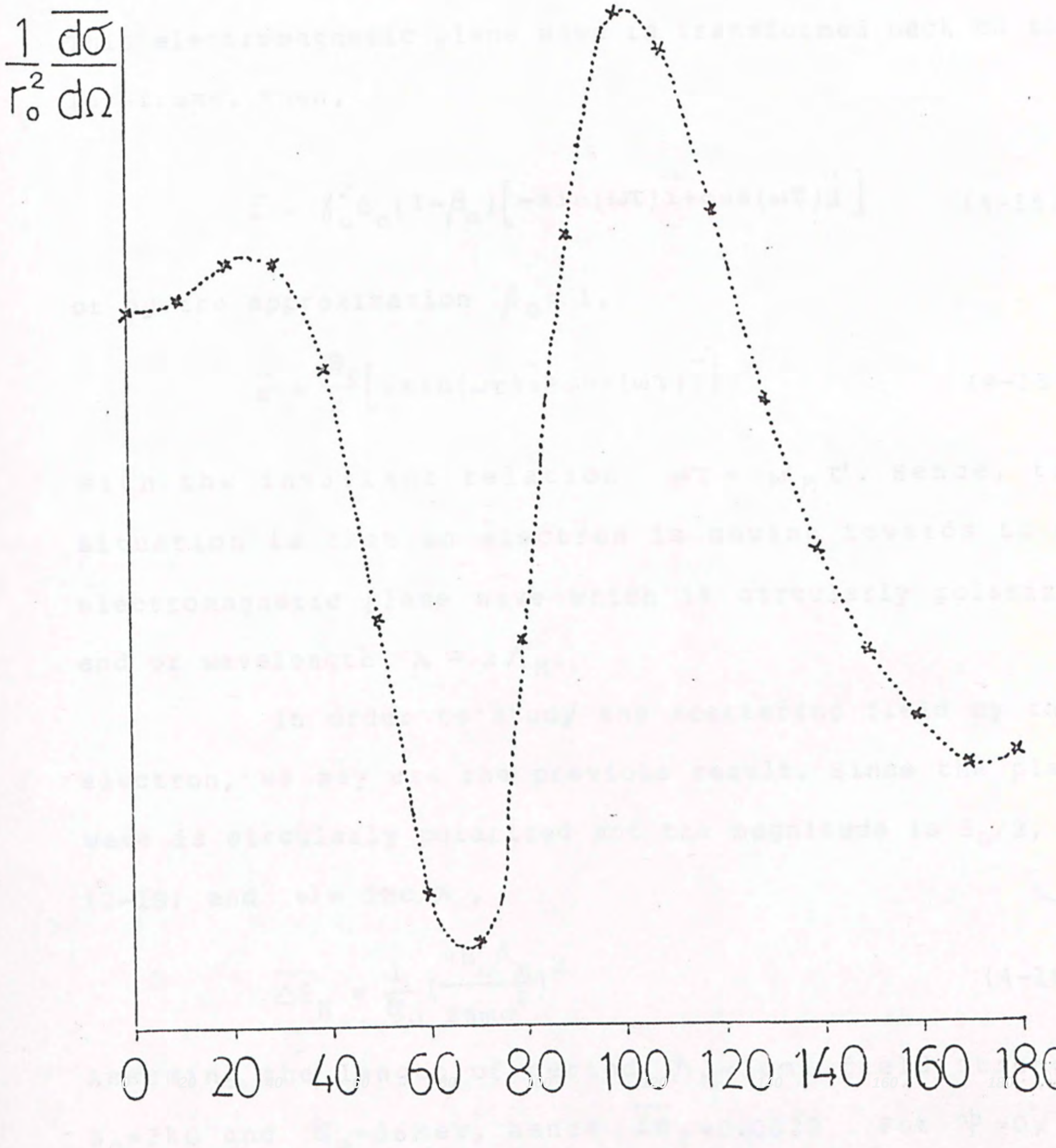
Suppose the field is given by,

$$\vec{B} = B_o\left[\cos\left(\frac{2\pi z}{\Lambda_M}\right)\vec{i}+\sin\left(\frac{2\pi z}{\Lambda_M}\right)\vec{j}\,\right] \tag{4-12}$$

that is, this field is periodic along the z-axis with length of period Λ_M and circularly polarized on the plane perpendicular to z-axis. The relativistic electron is travelling along $+\vec{z}$ direction with initial velocity $c\vec{\beta}_o$ and total energy $mc^2\gamma_o$, then in the electron rest frame this magnetic field is transformed as

$$\vec{E}' = \beta_o\gamma_o B_o\left[-\sin(\omega'_M\tau')\vec{i}'+\cos(\omega'_M\tau')\vec{j}'\right]$$
$$\vec{B}' = \gamma_o B_o\left[\cos(\omega'_M\tau')\vec{i}'+\sin(\omega'_M\tau')\vec{j}'\right] \tag{4-13}$$

where $\omega'_M = 2\pi\gamma_o c\beta_o/\Lambda_M$ and $\tau' = t'+z'/c\beta_o$. Assuming $\beta_o \approx 1$, the transformed field is approximately a plane wave



$\overline{\Delta\epsilon}_K = 0.1 \quad \phi = 0^\circ \;, \; \beta_0 = 0$

Figure 4-23

of angular frequency ω'_M, advanced time τ' and propagating in $-\vec{z}'$ direction. The electric field vector of this plane wave is

$$\vec{E}' \simeq \gamma_o B_o \left[-\sin(\omega'_M \tau')\vec{i}' + \cos(\omega'_M \tau)\vec{j}' \right] . \qquad (4\text{-}14)$$

This electromagnetic plane wave is transformed back to the lab-frame, then,

$$\vec{E} = \gamma_o^2 B_o (1-\beta_o) \left[-\sin(\omega\tau)\vec{i} + \cos(\omega\tau)\vec{j} \right] \qquad (4\text{-}15)$$

or by the approximation $\beta_o \approx 1$,

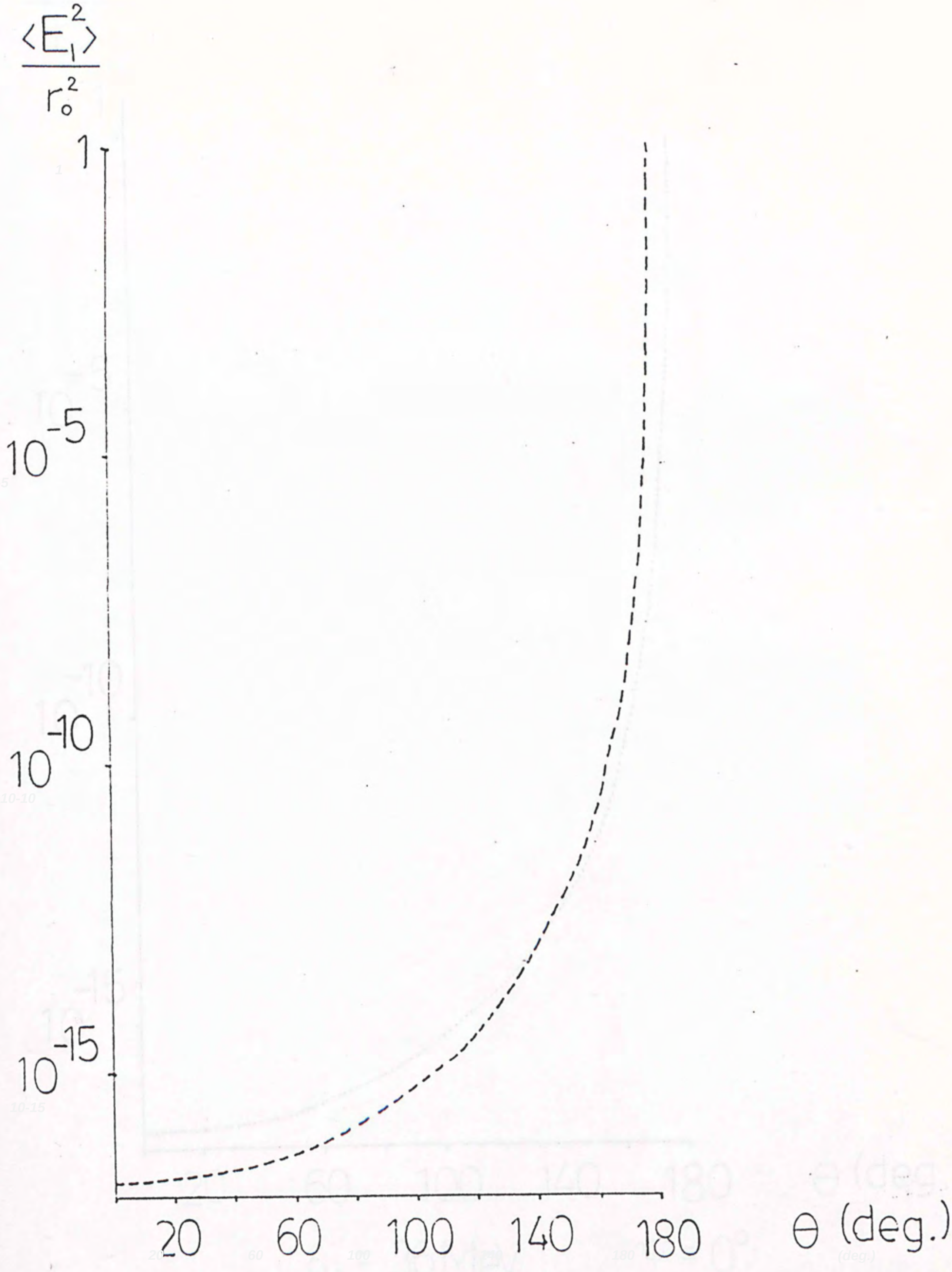
$$\vec{E} \simeq \frac{B_o}{2} \left[-\sin(\omega\tau)\vec{i} + \cos(\omega\tau)\vec{j} \right] \qquad (4\text{-}15')$$

with the invariant relation $\omega\tau = \omega'_M \tau'$. Hence, the situation is that an electron is moving towards to an electromagnetic plane wave which is circularly polarized and of wavelength $\lambda \simeq 2\Lambda_M$.

In order to study the scattering field by this electron, we may use the previous result. Since the plane wave is circularly polarized and the magnitude is $B_o/2$, by (2-18) and $\omega = 2\pi c/\lambda$,

$$\overline{\Delta\epsilon}_K = \frac{1}{\alpha_o} \left(\frac{eB_o\Lambda_M}{2\pi mc^2} \right)^2 . \qquad (4\text{-}16)$$

Assuming the length of period Λ_M=3cm, field strength B_o=2kG and $\mathcal{E}_o$=36MeV, hence $\overline{\Delta\epsilon}_K$=0.0022 . For $\psi = 0^\circ$, we have the average intensity of the polarization and scattering cross section as shown in figures 4-24 and 4-25.



$\varepsilon_0 = 36$ MeV $\quad \Psi = 0°$

Figure 4-24(a)

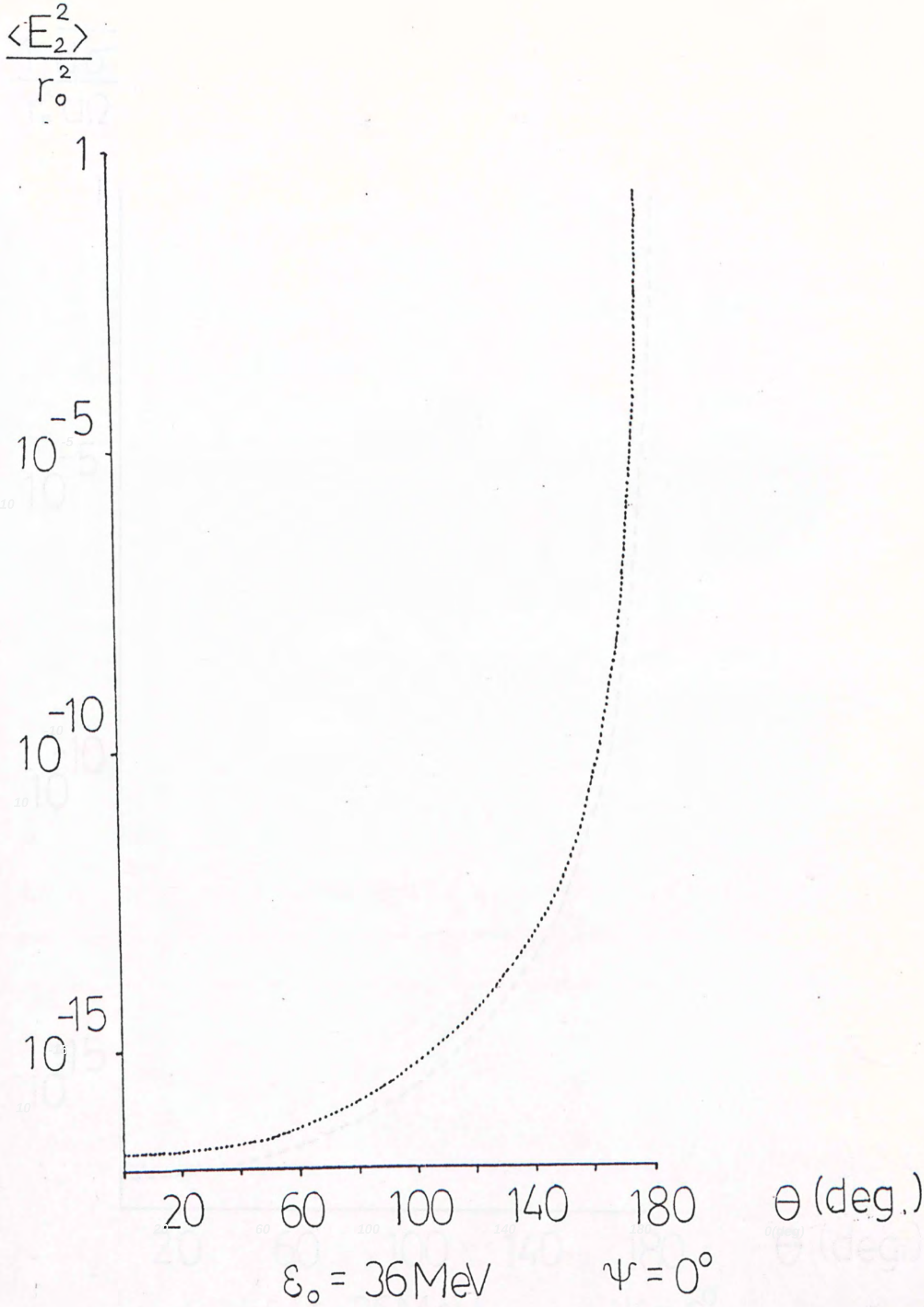
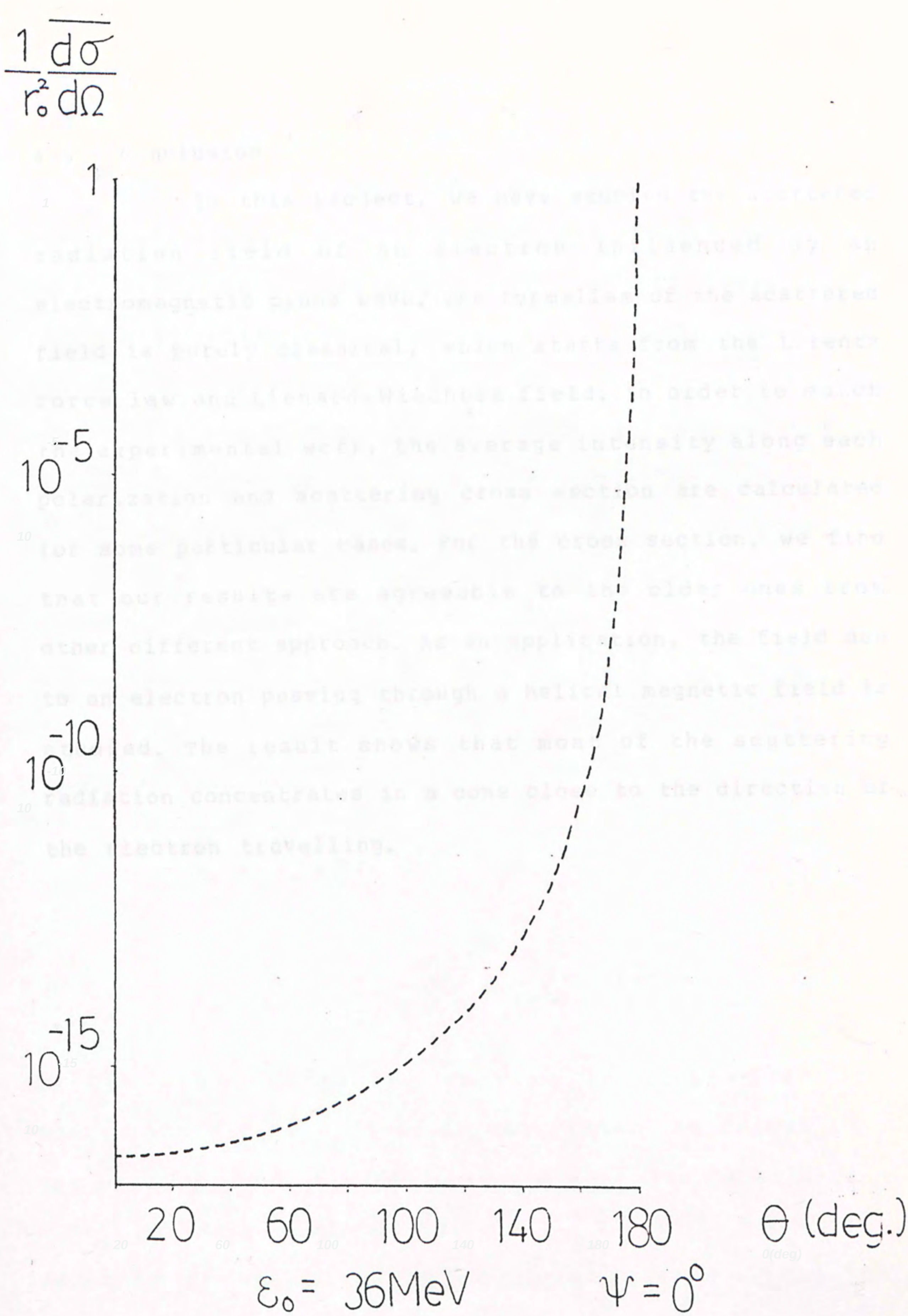

$\frac{\langle E_2^2 \rangle}{r_o^2}$
1
10^{-5}
10^{-10}
10^{-15}
20
60
100
140
180
θ (deg.)
ε_o = 36 MeV
$\psi = 0°$

Figure 4-24(b)



$\frac{1}{r_o^2}\overline{\frac{d\sigma}{d\Omega}}$
1
10^{-5}
10^{-10}
10^{-15}
20
60
100
140
180
θ (deg.)
$\varepsilon_o = 36MeV$
$\Psi = 0^o$

Figure 4-25

4.5 Conclusion

In this project, we have studied the scattered radiation field of an electron influenced by an electromagnetic plane wave. The formalism of the scattered field is purely classical, which starts from the Lorentz force law and Lienard-Wiechert field. In order to match the experimental work, the average intensity along each polarization and scattering cross section are calculated for some particular cases. For the cross section, we find that our results are agreeable to the older ones from other different approach. As an application, the field due to an electron passing through a helical magnetic field is studied. The result shows that most of the scattering radiation concentrates in a cone close to the direction of the electron travelling.

APPENDIX

In the previous chapters, we have assumed the plane wave exists at all time. However, in reality the plane wave appears after the laser has been switched on. Considering this condition, the electric field of a circularly polarized plane wave in (2-15) should be modified by multiplying a factor $g(\tau)$. It is varies slowly such that the field is zero outside the laser pulse and is still $\vec{E}(\tau)$, i.e. $g(\tau) = 1$, within the pulse. Moreover, $\frac{dg(\tau)}{d\tau}$ is equal to zero in the main part of the pulse. Hence, $\vec{E}(\tau)$ in (2-15) is replaced by,

$$\hat{E}(\tau) = \frac{iE_o}{\omega}\frac{d}{d\tau}g(\tau)e^{i\omega\tau} \quad . \tag{A-1}$$

Then, by (2-8) we have,

$$\hat{p}_m = i\frac{eE_o}{\omega}g(\tau)e^{i\omega\tau} \tag{A-2}$$

$$p_n = \gamma_o\beta_o + \frac{1}{2\alpha}\left(\frac{eE_o}{mc\omega}\right)^2 = \gamma_o\beta_o + \frac{\overline{\Delta\epsilon_K}}{2} \tag{A-3}$$

By the same procedures we used in chapter 4, the scattering electric field is calculated. In figure A-1, the pattern shows the electric field on its polarization plane in one period for $\overline{\Delta\epsilon}_K = 0.1$, $\theta = 90^\circ$, $\psi = 90^\circ$ and velocity of the electron $= -0.5c\vec{n}$. Also the angular distribution of the average intensity along the two polarization directions and scattering cross-section is calculated by computer, as shown in figures A-2 and A-3.

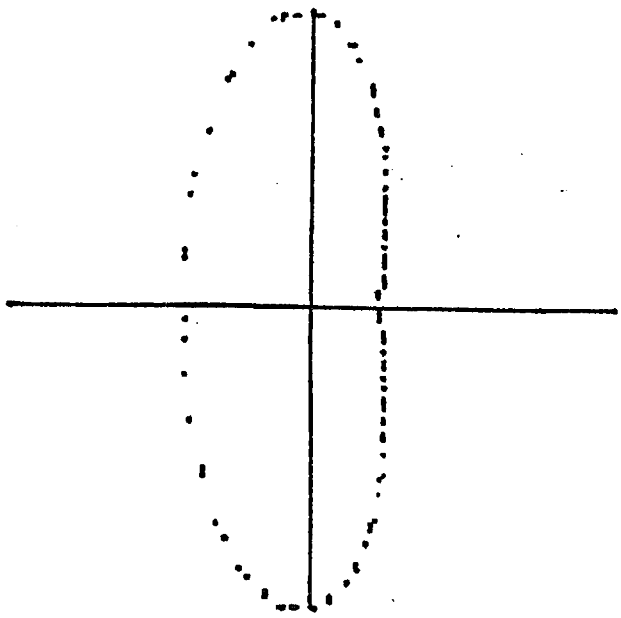


Fig. A-1

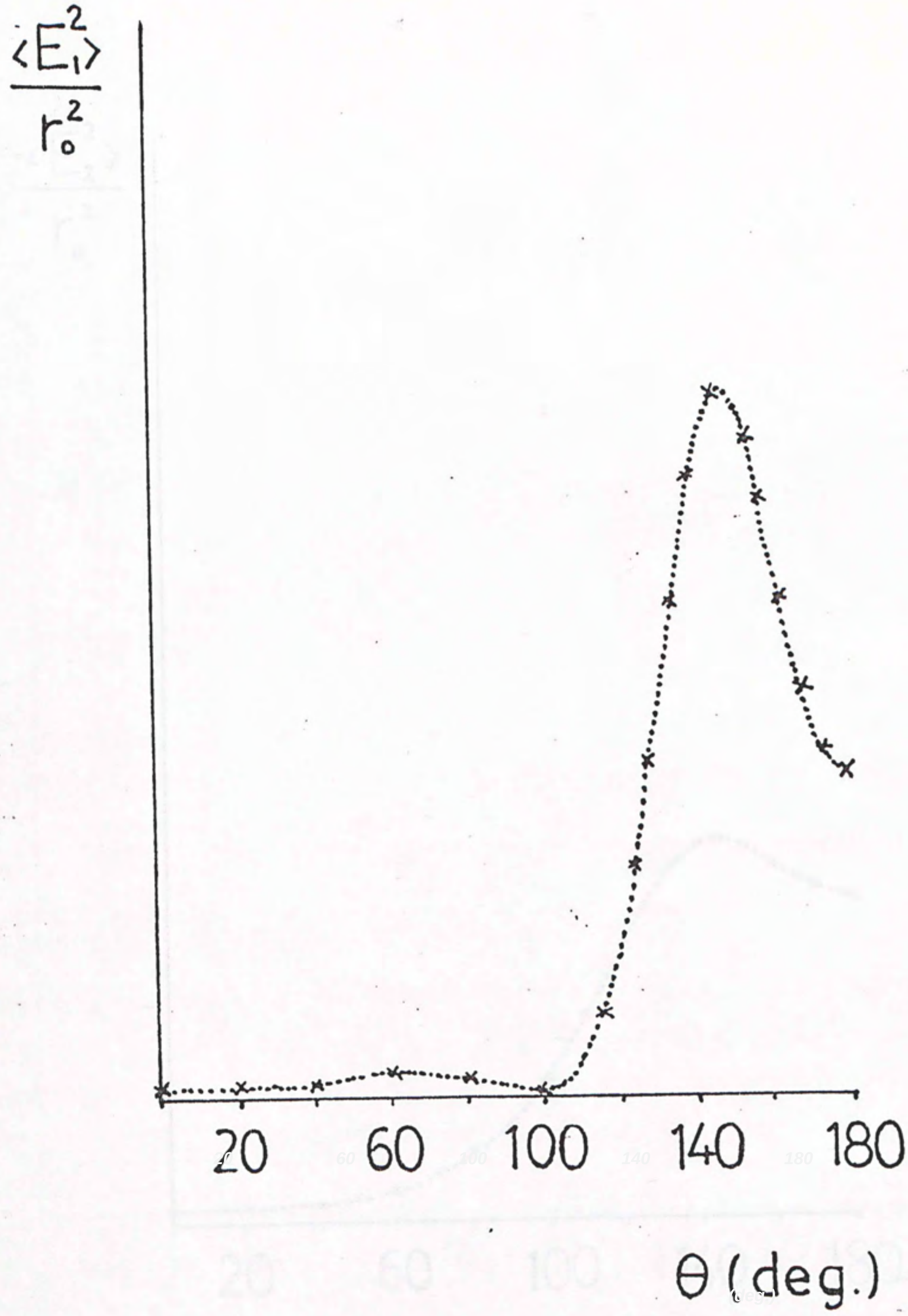


Fig. A-2 (a)

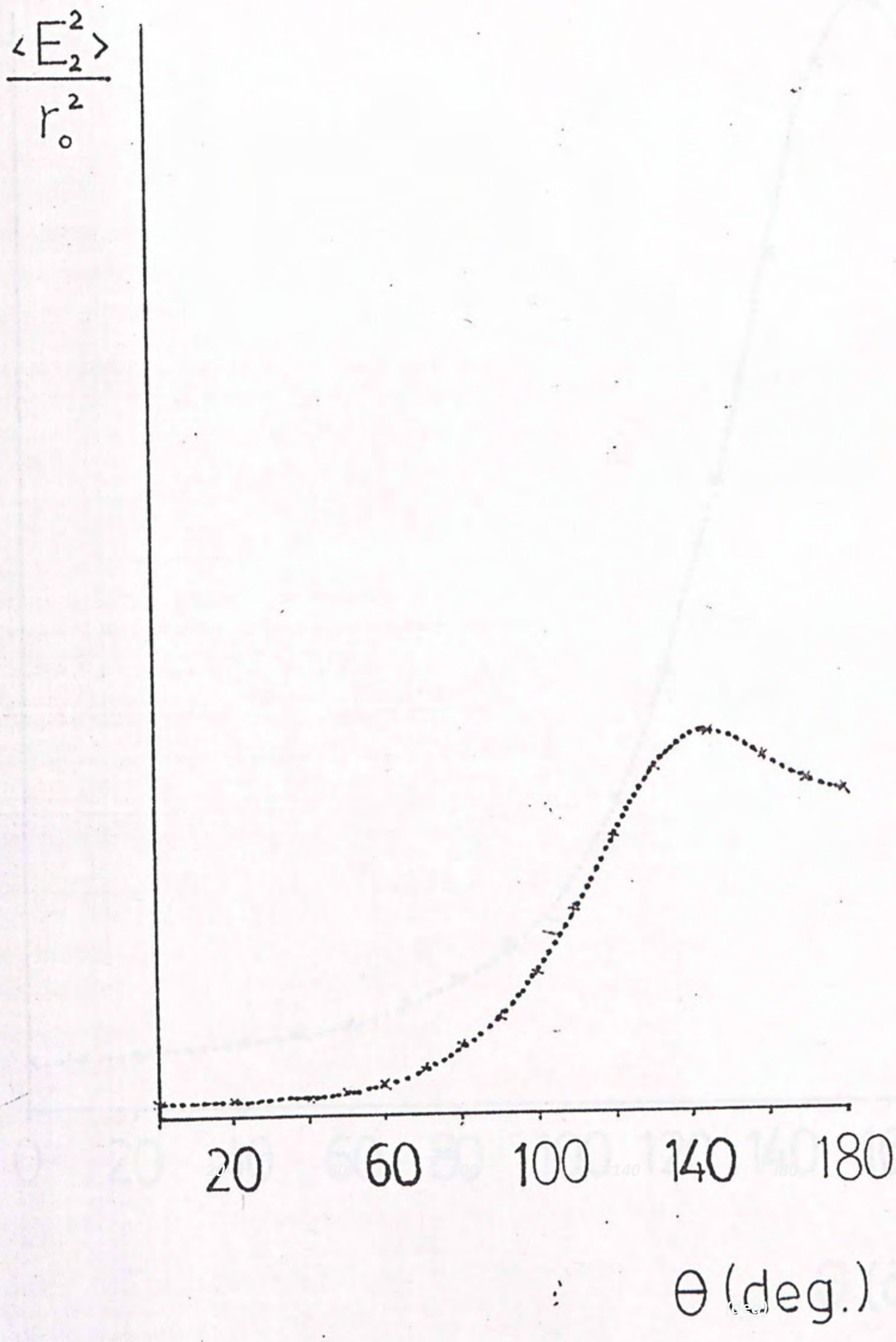
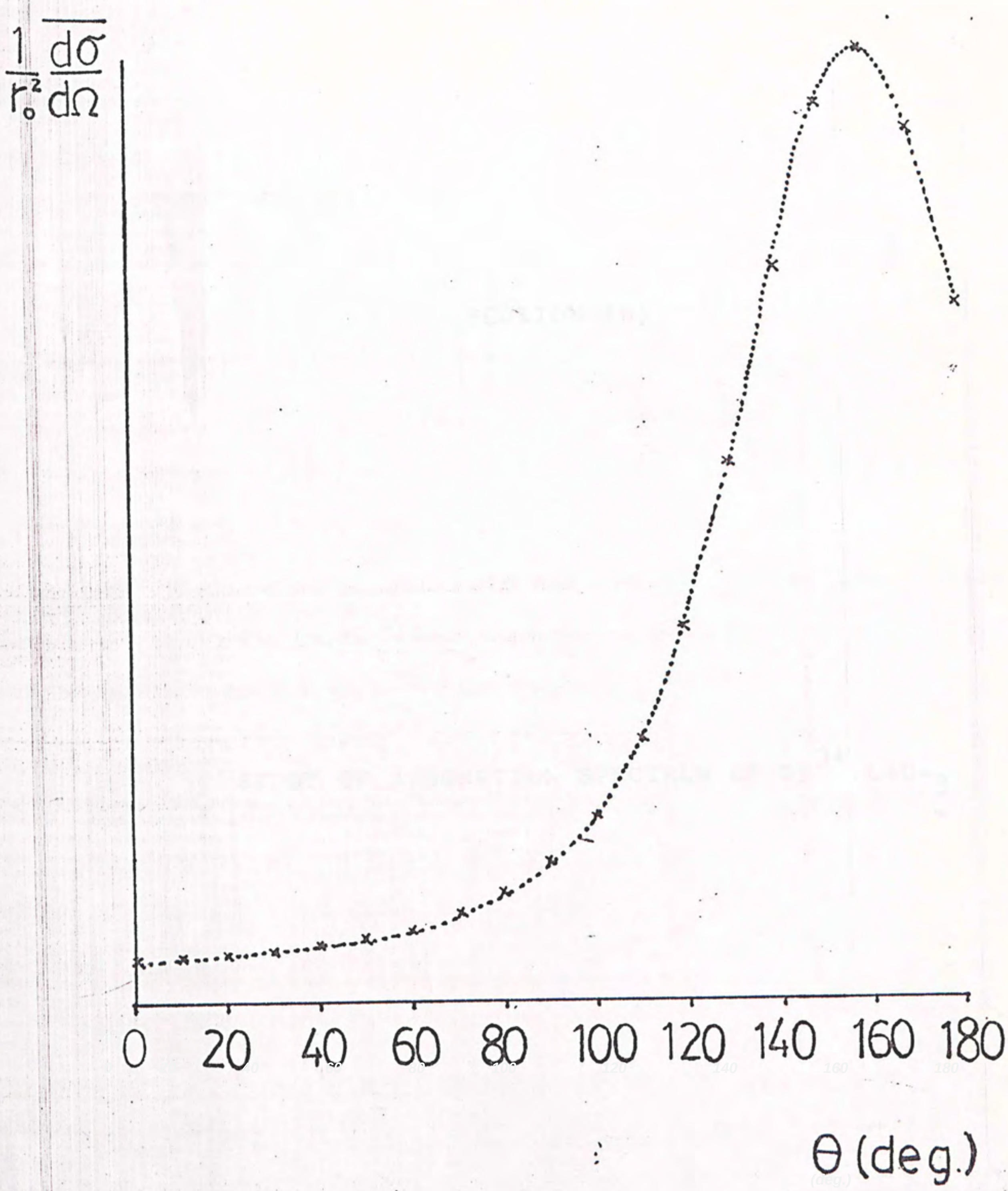


Fig. A-2 (b)



$\frac{1}{r_0^2}\overline{\frac{d\sigma}{d\Omega}}$
0
20
40
60
80
100
120
140
160
180
θ (deg.)

Fig. A-3

SECTION (B)

STUDY OF ABSORPTION SPECTRUM OF $Dy^{3+}:LaCl_3$

Chapter 1

INTRODUCTION

The rare earth elements have the most complicated spectra due to the imcomplete 4f shell, which produces many low-lying energy levels. The study of the spectra of rare earths progressed rapidly after World War II.

The result of studying the absorption and fluorescence spectra of rare earth ions in crystals was fruitful[1,4]. Through the study of these spectra, one can understand the stucture of the sharp energy levels of the ion. In this thesis the ion of interest is dyspronium in the $LaCl_3$ crystal. There were many previous results on this ion in other crystalline lattice[5]. The most important one about the triply ionized dyspronium in $LaCl_3$ was reported by H. M. Crosswhite and G. H. Dieke[3]. The present study is an extension of their work. A more detailed description is presented in the next two chapters.

In chapter 4, there is a brief description about the experimental procedures. In the chapter following, the results are presented. The wavelengths of the spectral lines and the energy level scheme are tabulated. An extended energy level scheme is obtained from the measurement.

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Moreover the Zeeman effect of the energy levels is studied and a plot of the wavenumbers versus the magnetic field is presented. From the graphs it can be seen the splitting of the energy is linear against the magnetic field when the field is small and is quadratic when the field becomes larger. The results are analyzed too.

Chapter 2

THE STUDY OF THE SPECTRA OF RARE EARTH IONS IN CRYSTALS

2.1 The purpose of the study

When the electrons of an atom or ion jump from one state to another, light of a characteristic frequency, which corresponds to the difference of the energy of these two states, is emitted or absorbed. The light of different frequencies or wavelengths is dispersed by a grating into a spectrum and is photographed on a photographic plate.

These spectral lines are usually used to identify elements in many aspects. Since the lines of various wavelengths correspond to the states of an atom or ions, most of the information of the energy level scheme of the atom or ion can be obtained through an analysis of the line structure of the spectrum.

The ions of rare earths can be incorporated into a crystal lattice and retain their sharp energy levels which are only slightly modified by the crystal field. Hence, it is possible to obtain some of the energy levels from the absorption or fluoresence spectra of the rare earths ions in crystals. The study will lead to an understanding of the complex structure of the energy levels, and of the influence of the crystal field.

One can place the rare earth ions in an external magnetic field and study the splitting of spectral lines by the Zeeman effect. Through the Zeeman splitting, one can obtain information about the magnetic properties of the rare earth ions in the crystalline environment, and then assign the crystal quantum numbers. In our research work, the ion being studied is triply ionized dysprosium Dy^{3+}.

2.2 Historical background

It was known in the early time that some solids and crystals, including rare earths, had sharper absorption spectra. However not much progress was made at that time due to the crude technique and the impure samples. This difficulty was overcome after World War II because pure rare earth elements were available.

In 1906, J. Becquerel discovered that the spectral lines became sharper when the temperature was lowered and that the absorption lines would show a Zeeman splitting in an external magnetic field. These techniques were helpful in studying spectral lines.

After the establishment of quantum mechanics there was progress in the theoretical work. H. Bethe showed that the absorption lines split under the effect of the internal electric crystalline field. In the late thirties, it was realized that the sharp-lines in the absorption spectra in rare earths came from forbidden transitions within the 4f shells.

Because of the progress in the theoretical work, the foundations were clarified. The experimental work was to identify the observed structure with the theoretical prediction. Studies of transitions between the Zeeman components in the rare earth started in the fifties when many research groups were engaging paramagnetic resonance experiments. For example, the study of Zeeman splitting of the absorption spectrum of Dy^{3+} ions in $LaCl_3$ was reported by Dieke and Crosswhite in 1961[3] and the present research work is an extension of that into ultraviolet region.

For details the best reference is the book "Sprctra and Energy Levels of Rare Earth Ions in Crystals" by G. H. Dieke (1968)[1].

2.3 The sharp-line spectra

In order to produce sharp spectral lines of ions, there should be a regular surrounding for the ions. The surrounding should not have fluctuations in time and should be the same for all ions of the same kind. Furthermore, the ions must not interact with the neighbours of the same kind.

To fulfil the former requirement, we can study the ions in crystals at very low temperature. The second requirement is also satisfied if the valence electrons of one ion are shielded from those of another. That is, the valence electrons should stay in the inner orbit such that the outer electron shells screen the effect of the neighbouring ions. Under this situation, the valence electrons of one ion do not interact with the electrons of the neighbouring ions. The rare earth elements, whose valence electrons are in 4f orbits, have complete shells outside the 4f-orbits and fulfil the second requirement.

2.4 The rare earth elements

The rare earth elements, also known as lanthanides, are the most complicated ones. Each rare earth element has several dozens of electrons. The lanthanides are a group of elements which have an open 4f shell. Usually the lanthanides are in the form of triply ionized atoms in crystals. The electronic configurations of these trivalent ions are in general as:

$$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 4f^n 5s^2 5p^6$$

with n varies from from 1 to 14 for Ce^{3+} to Lu^{3+}. That is, they have a xenon core, which contains 54 electrons and n 4f electrons. For example, Dy^{3+} ions has nine 4f electrons. (The neutral atom Dy has an electronic configuration of xenon core + $4f^{10}6s^2$.)

To study the spectra and energy levels of the rare earth ions, one may investigate the spectra of a neutral atom, a singly ionized, a doubly ionized or a triply ionized atom, namely the first, second, third and forth spectra respectively. In the first and second spectra, the spectra are too complicated to analyze due to the nearly coincidence of the many low-lying configurations. The third and forth spectra are simpler, especially the forth spectra, where the separation between the various configurations is so large that the lines become sharp. Hence the interest is in the triply ionized rare earth in crystals. In fact, the properties of the trivalent ions are very different from that of the neutral atoms. For example, the ground state of Dysprosium atom is $^5I_8$, but that of Dy^{3+} ion is $^6H_{15/2}$. In the following, the term "rare earths" should always mean the trivalent ions of rare earths in crystals.

The symmetry of the host crystal has a large effect on the spectral lines. Usually host crystals of higher symmetry are chosen so that the theoretical work can be treated more easily. Anhydrons chlorides, such as $LaCl_3$, YCl_3, etc. are commonly used as the host crystals. For the crystal $LaCl_3$, the lattice has a symmetry of C_{3h}. The crystalline structure is hexagonal and the crystal axis is the rotational symmetry axis. When Dy^{3+} ions are diffused into the crystal, the Dy^{3+} ions replace some of the La^{3+} and therefore the ion site symmetry is C_{3h} too. The crystals are grown out from the aqueous solutions, hence the percentage ratio of Dy:La is easy to control.

Chapter 3

THEORETICAL DISCUSSION OF Dy^{3+} IONS

3.1 The wavefunctions and the Hamiltonian[1,2]

A free Dy^{3+} ions has spherical symmetry. Hence only the radial wavefunctions R_{4f} are needed. The eigenenergy E is calculated by the dot product $\langle R_{4f}|H|R_{4f}\rangle$ directly from the Hamiltonian H.

Since there are 63 electrons in a Dysprosium ion, it is impossible to solve the Schrodinger's equation for such a complicated system. A relatively simple method is to use the hydrogen-type wavefunction with empirical parameters. For 4f electrons, the radial wavefunctions are in form of[2a]

$$R_{4f}(r) = \frac{1}{96\sqrt{35}}(Z-\sigma)^{3/2} r^3 \exp(-r/2) \qquad (3\text{-}1)$$

where Z is the atomic number and σ is a screening parameter.

A more effective theory to treat this problem is the Hartree-Fock approximation. The solutions for rare earth ions were computed by A. J. Freeman, R. E. Watson and O. J. Sovers in the form[2b]

$$R_{4f}(r) = \sum_{i=1}^{4} C_i r^3 \exp(-Z_i r) \qquad (3\text{-}2)$$

The coefficients C_i and Z_i are shown in table 3-1.

Table 3-1

Ion name	Dy^{3+}
Ground level	$^6H_{15/2}$
Ground level configuration	$4f^9 5s^2 5p^6$
Ionic radius	0.908 Å
C_1 = 2480.40	Z_1 = 13.463 au
C_2 = 448.837	Z_2 = 7.529 au
C_3 = 55.9670	Z_3 = 5.019 au
C_4 = 2.35247	Z_4 = 2.762 au

Because of the spherical symmetry, the energy levels are degenerate. The dominant interactions are the Coulumb interaction and the spin-orbit interaction. For rare earth ions, the former is dominant. Hence L-S coupling (Russell-Saunders coupling) is applied.

The Coulomb interaction between any one electron and the nucleus and between two electrons is described by

$$H_c = -\frac{Ze^2}{r_i} + \frac{e^2}{r_{ij}} \qquad (3\text{-}3)$$

in c.g.s. unit. For spin-orbit interaction the corresponding Hamiltonian is approximately,

$$H_{LS} = \zeta(r_i)\vec{l}_i \cdot \vec{s}_i \qquad (3\text{-}4)$$

where $\zeta(r_i)$ is the spin-orbit coupling function:

$$\zeta(r_i) = \frac{\hbar^2}{2m^2c^2r_i}\left(\frac{\partial V(r_i)}{\partial r}\right) \qquad (3-5)$$

Other effects, such as the hyperfine structure (10^{-2} - 10^{-3} cm^{-1}), nuclear quadrupole interaction and relativistic effects, are relatively small compared with H_C and H_{LS}. Therefore, neglecting them, the Hamiltonian for this system is

$$H = -\sum_i \frac{\hbar^2}{2m}\nabla_i^2 - Ze^2\sum_i \frac{1}{r_i} + \sum_{ij}\frac{e^2}{r_{ij}} - \frac{\hbar^2}{2m^2c^2}\sum_i \frac{1}{r_i}\left(\frac{\partial V(r_i)}{\partial r}\right)\vec{\ell}_i\cdot\vec{s}_i \qquad (3-6)$$

3.2 The ground level of Dy^{3+} ion

The configuration of Dysprosium ion is a Xenon core and nine 4f electrons. By the L-S coupling and consideration of the Pauli exclusion principle, we can find the possible ground level, in terms of the spectroscopic notation: ^2S, ^4S, ^2P, ^4P, ^6P, ^2D, ^4D, ^2F, ^4F, ^6F, ^2G, ^4G, ^2H, ^4H, ^6H, ^2I, ^4I, ^2J, ^4J, ^2K, ^4K, ^2L, ^4L, ^2M and ^2N.

Because the highest multiplicity is 6, the highest total orbit angular momentum L is H among ^6H, ^6F and ^6P from the Hund's rule. Since the shell is more than half filled for Dysprosium ion, the ground level should be $^6H_{15/2}$. This was experimentally confirmed by H. M. Crosswhite and G. H. Dieke in 1961[3]. The next few higher levels are ${}^6H_{13/2}$, ${}^6H_{11/2}$, ${}^6H_{9/2}$, ${}^6F_{11/2}$, ..., ${}^6F_{1/2}$, which were also reported in their paper.

3.3 The crystal field

Usually the ions are in a crystal of certain symmetry. For example, in this research, the Dy^{3+} ions are in a piece of single crystal $LaCl_3$, which has the symmetry C_{3h}. Neglecting some dynamic interactions in the lattice, the ions are considered as being placed in a static electric field, which arises from the ions of the host crystal; such a field is call a crystal field. The presence of the crystal field will modify the energy levels and radial wavefunctions of the free ions.

We can use the following potential to describe the crystal field approximately,

$$V(\vec{r}) = \sum_i \frac{eZ_i}{|\vec{r}-\vec{R}_i|} \tag{3-7}$$

where r is the position of the rare earth ion, R_i is the position of the neighbouring ion and Z_i is the charge of the R_i ion. Expanding in spherical harmonics(2c), we have

$$V_F(\vec{r}) = \sum_\ell \sum_{m=-\ell}^{\ell} \left[\sum_j \frac{4\pi}{2\ell+1} \frac{Z_j}{R_j^{\ell+1}} (-1)^m Y_\ell^{-m}(\vec{R}_j) \right] r^\ell Y_\ell^m(\vec{r})$$
$$= \sum V^m_\ell \; . \tag{3-8}$$

Usually the expression in the square bracket is treated as experimental parameters. For C_{3h}, only $V^o{}_2$, $V^o{}_4$, $V^o{}_6$, $V^6{}_6$ and $V^{-6}{}_6$ are non-zero.

For an ion containing an odd number of electrons, J is a half-integer. In a C_{3h} crystal symmetry field, group theory gives that all levels are doublets and will split into J+1/2 Stark components. Therefore the ground level of Dy^{3+} (J=15/2) will split into 8 components. The existence of the crystal field potential gives rise to an interaction between the states characterized by (α, J, M) and (α', J', M+q) in the crystal, and the quantum number M for the z-component of angular momentum is no longer a good quantum number. In order to keep a good quantum number, a new parameter, the crystal quantum number μ was introduced by Hellwege as a good quantum number. Hence, each component due to the crystal field effect is represented by μ , defined by

$$J_z = \mu \pmod q \tag{3-9}$$

q is a parameter depending on the site symmetry. For $LaCl_3$, which is hexagonal, q = 6 . Since the ground state, J = 15/2; therefore J_z is $\pm 15/2$, $\pm 13/2$, $\pm 11/2$, $\pm 9/2$, $\pm 7/2$, $\pm 5/2$, $\pm 3/2$ and $\pm 1/2$. Hence μ for Dy^{3+} is found as $\pm 1/2$, $\pm 3/2$ and $\pm 5/2$ by the (mod 6) condition.

Since each level will split into several Stark components, the spectrum of Dy^{3+} ions at 4K or lower is interesting. At such low temperature, the lowest component of the ground state will be highly populated according the Boltzmann's distribution law. Most of the lines arise from the lowest ground level to the Stark components of the exicted levels. When the temperature is increased, new lines appear due to transition to the Stark components of the ground level.

For forced electric dipole transitions, quantum number μ is subject to a selection rule. For Dy^{3+}, the number of electrons is odd ; J and μ are half integer, the selection rule for transitions between μ' and μ'' may be summarized as following,

μ'' \ μ'	1/2	3/2	5/2
1/2	-	σ	$\sigma\pi$
3/2	σ	π	σ
5/2	$\sigma\pi$	σ	-

where σ means the polarization is perpendicular to the crystal axis and π means the polarization is parallel to the crystal axis while $\sigma\pi$ means the transition is unpolarized. The selection rules and polarization properties are important in identifying μ.

3.4 The Zeeman effect

As a result of quantum mechanical consideration, a level will split into 2J+1 components in an external magnetic field; this is due to the existance of a magnetic dipole moment $\vec{\mu} \propto (\vec{L}+\vec{S})$ of each ion. At low temperature, if the external field is relatively weak, one can obtain Zeeman splitting of energy levels. When the external field is so strong that the LS coupling is no longer satisfied, one then has the Paschen-Back effect.

The interaction of a weak field is represented by a Hamiltonian for a free ion,

$$H_B = -\vec{\mu}\cdot\vec{B} \qquad (3\text{-}10)$$

in which $\vec{B}$ is the magnetic field. The energy shift is,

$$S = gM\beta B \qquad (3\text{-}11)$$

where M is the magnetic quantum number, g is the Landé g factor and β is the Bohr magneton. For the ground level of the Dy^{3+} ion, because L=5, S=5/2 and J=15/2, the g factor is $g_o = 1.333$. For LS coupling g is the same as g_o but in general g is not equal to g_o.

In Lorentz unit βB (for B = 21.351 kgauss, $1\beta B = 1 cm^{-1}$), the splitting between states of M and -M is,

$$S = 2gM \qquad (3\text{-}12)$$

which is a scalar quantity.

For the ions in a crystal field, because of the influence of the crystal field, M is no longer a good quantum number. One is supposed to use the crystal quantum number μ. Usually each μ value does not necessarily represent only one state. The splitting is designated by S_1 when $\vec{B}$ is parallel to the crystal axis.

Under the first order approximation, the splitting is linear in B. When the magnetic field is strong enough that the magnetic interaction is as large as the Stark splitting, then a nonlinear Zeeman effect is evident. The dependence on B is quadratic[1].

Chapter 4

EXPERIMENTAL PROCEDURES

The crystal used for the study was grown from aqueous solution of $LaCl_3$ and $DyCl_3$ where the Dy concentration was 1%. The sample was mounted such that the crystal axis was oriented in a chosen direction.

The absorption spectra were photographed by Prof. R. S. Rana and Prof. F. W. Kaseta during the late seventies. All the spectra were obtained at low temperature of 4.2 K with a dual grating spectrograph manufactured by Bausch and Lomb and recorded in polarized light using Halogen Tungsten lamp and polaroid sheets.

Becuse the light from the lamp was unpolarized, the polarized light was obtained by using a polaroid sheet. The polaroid sheet was placed between the lamp and the sample. By rotating the polaroid sheet, the light can be polarized either perpendicular or parallel to the crystal axis. If the polarization is perpendicular to the crystal axis, the spectral lines photographed on the plate were σ-polarization lines. If the polarization is parallel to the crystal axis, one can get the π-polarization lines.

The spectra at various field strengths were photographed in the second-order. During the experiment the spectrograph was adjusted for taking first-order spectral lines. However, by placing a filter before the spectrograph, second-order spectral lines in the ultraviolet region were photographed.

The Zeeman splitting of the absorption spectra were recorded too. The magnetic field was supplied by the water-cooled Bitter magnets at the National Magnet Laboratory (MIT) in Cambridge, Massachusetts, U.S.A.. The magnetic field could be varied up to about 100kG. The maximum field was reached at a current of about 20kA through the solenoid. Field strength is measured in terms of this current. For the region of wavelength 3500 – 3900 Å, 1kA corresponds to 4.64 kG; for region 3000 – 3450 Å and 3700 – 4100 Å, 1kA corrsponds to 4.97 kG and for region 2500 – 3000 Å, 1kA corresponds to 5.01 kG. The spectra measured in this research were photographed in the external magnetic field whose direction is parallel to the crystal axis.

The wavelengths of the absorption spectra were measured by means of a travelling microscope. The smallest unit which can be read is 1 micron and the reciprocal plate factor is approximation 17 to 20 Å/cm. The wavenumber in vacuum corrsponding to each measured wavelength in air was computed by using the Edlen's formula(7) with the help of a computer.

The intensity of each spectral line is estimated usually in a ten-point scale, i.e. the line intensity is represented by a number from 0 to 10. "0" means that the line is so weak that it cannot be discernible. The symbol "00" means that the line is imagined to exist. The line width or the "nature" of the spectral line is described by a letter or a combination of letters. "s" indicates that the line is sharp and "ss" is for "very sharp". "b" is for a "broad"; "bb" is for a "very broad" and "d" is for a diffused line.

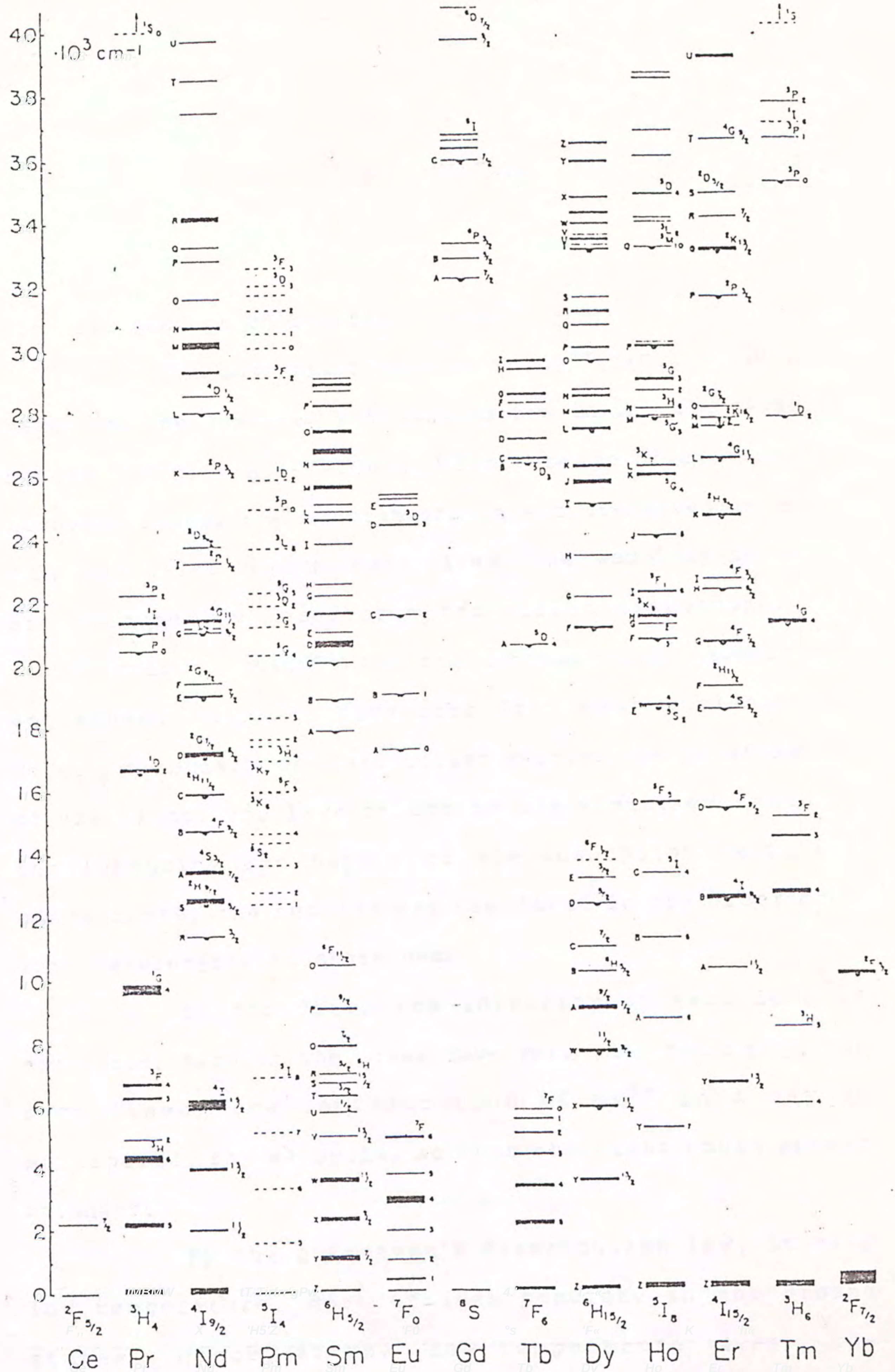

Figure 5-1 Observed energy levels of the triply ionized rare earths (Ref. 4).

Chapter 5

RESULTS AND ANALYSIS

5.1 The absorption spectra

The absorption spectra of Dy^{3+}:$LaCl_3$ at 4K were measured. The observed wavelengths are in the ultra-violet region of 2500 Å — 4100 Å. With absence of an external magnetic field, the wavelengths in air are given in table 5-1. The first column λ(Å) gives the wavelengths which are measured by means of a travelling microscope. The second column $\tilde{\nu}$ (cm^{-1}) is the corresponding wavenumbers in vacuum, which is converted from the wavelength by Edlen's formula. The third column denotes the polarization of the light. The last column is the visual estimate of the intensity and nature of the absorption line. For convenience, the results are tabulated in the order from long wavelengths to short ones.

In our data, the intensity of each line is estimated. Some of the lines have very weak intensity. For such lines, the concentration of Dy^{3+} ions may be multiplied, say 2% Dy:La, so that the lines could appear stronger.

By the Boltzmann's distribution law, at very low temperature, most of ions populate in the ground states. Hence, at the low temperature (4.2K), the absorption of light takes place only from the ground level to higher excited levels of the ion. An analysis of the absorption spectra give the energy of the excited levels.

5.2 The Zeeman effect

The Zeeman splittings of the levels of Dy^{3+} in $LaCl_3$ crystal with the external magnetic field vector parallel to the crtstal axis are studied. The magnetic field is varied in a rather wide range.

The absorption spectra of the Dy^{3+} ions at each magnetic field B are observed. The wavelengths and wavenumbers, in the range of 2900 Å — 4100 Å, are tabulated in tables 5-4 to 5-27 in accordance with the magnet currents. In these tables, the data are arranged according to the polarization of the lines separately. The first column is the wavelengths in air that we measured. Then , the wavenumbers in vacuum are in the second column, which are followed by its estimated intensity and nature. The datum in the left hand side is for the σ-polarization and that in the right hand side is for the π-polarization. For each table, the magnetic field is denoted by the magnetizing current in kiloamperes.

For all the lines that were measured, graphs of wavenumbers were plotted versus the magnetic field, as shown in figures 5-2(a) to 5-2(w). In the figures, the points for σ-polarization are denoted by " ⊙ " and the points for π-polarization are denoted by "x".

Obviously from the plot we can see that some lines split linearly, as given by the Zeeman effect formula (3-11), and some are curved. The nonlinear lines appear because the magnetic splitting of the crystal levels becomes of the same order of magnitude as the field-free Stark splittings. In this case, the first order approximation is no longer satisfied. Hence, the nonlinearity of the lines may be considered as the Paschen-Back effect of the energy levels in the crystal. Some of those lines are shown in the figures.

5.3 The energy level scheme

After calculating the wavenumbers, the next step is the interpretation of the levels. That is to assign the quantum numbers or $^{2S+1}L_J$ symbols to the levels. Since the magnetic quantum number M is no longer a good quantum number in crystal, the angular momentum quantum number J becomes the most important one.

Because the absorption spectrum is due to the transitions from the ground levels to the higher excited levels, we can form the energy level scheme and assign the quantum numbers.

According to the Bohr theory, the order of the energy levels is 4f, 5d, 6s... ; however, in fact the electrons in these levels have nearly the same energy, especially in the rare earths. The neihbouring levels will overlap one another. Due to the higher nuclear charge and rather perfect screening, the situation is not too bad for rare earth ions. For Dy^{3+} ion, the lowest configuration is

$4f^9$ and then $4f^8 5d$, $4f^8 6s$, ... etc.[4].

Because of the influence of the crystal field, each level splits into several components. In the early days, studies on the energy levels gave the centers of gravity of the energy levels. As a summary, the results for rare earth ions are shown in figure 5-1[4].

For Dy^{3+} ions in crystal of $LaCl_3$, detailed analysis are available for the ^6H and ^6F levels. But beyond these low-lying levels, very few information could be found about the higher levels. Only about 28 levels from 20000 cm^{-1} to 36000 cm^{-1} were known so far.

From the previous results, the energy level scheme is obtained. As shown in table 5-2, the scheme is up to 39000 cm^{-1}. In the table, the SLJ symbol and experimental designation for each level is given in the first column. Then crystal quantum number μ and Zeeman splitting S_1 are in the following two columns. From μ , one can find the quantum number M by (3-9). Also by (3-12), one can find gM after simply deviding S_1 by 2 (in Lorentz unit). Usually the value of gM is denoted by <gM>. The following column is the energy level in cm^{-1} and its visual intensity estimate. The last one is its polarization.

The low-lying energy levels were already known[3]. Our results given energy levels higher than L (about 27000 cm^{-1}) and are completely new. Hence, in the right hand side of the table, the 20 levels which were reported in ref.3 are printed for comparison. We can see that agreement between their work and ours is quite good.

Moreover, the calculated centers of gravity of levels of $Dy^{3+}:LaF_3$ are shown in table 5-3, which were calculated by W. T. Carnall, H. Crosswhite and H. M. Crosswhite(6). Since the structure of LaF_3 is C_{2h}, which is completely different from $LaCl_3$, the numerical values of the energy levels are not the same, differing by about 200 cm^{-1}. But the SLJ symbols are most in the same order.

5.4 Conclusion

The absorption spectrum of $Dy^{3+}:LaCl_3$ at low temperation of 4.2 K was studied. Through a time-consuming analysis, we have obtained an empirical energy level scheme of the Dy^{3+} ions in crystal $LaCl_3$ up to 38923cm^{-1}. In fact the work is an extension of the energy scheme obtained by H. Crosswhite and G. H. Dieke (3).

As shown in table 5-2, we can see that our results beyond the energy level L are agreeable with the 20 levels which were reported in ref.3. From the good agreement with the old results, the extension of the energy level scheme is reliable.

Table 5-1 Absorption spectrum at B=0

λ(Å) (air)	$\tilde{\nu}$(cm^{-1}) (vac)	Pol.	I	Remark
4010.300	24,928.74	σ	3b	
4010.270	24,928.93	π	Ob	
4008.755	24,938.35	σ	3b	
4008.689	24,938.76	π	Ob	
4007.853	24,943.96	σ	1b	
3904.190	25,606.25	σ	3b	
3904.182	25,606.31	π	5b	
3902.715	25,615.93	π	5b	
3901.864	25,621.52	σ	3b	
3901.786	25,622.03	π	Obd	
3901.139	25,626.28	σ	3b	
3900.061	25,633.36	π	5b	
3899.117	25,639.57	π	3b	
3898.568	25,643.18	σ	00	
3897.219	25,652.05	σ	00	
3892.797	25,681.19	π	1	
3890.526	25,696.18	π	1	
3890.066	25,699.22	σ	0	
3889.684	25,701.75	σ	0	
3831.916	26,089.20	σ	5b	
3831.912	26,089.23	π	5b	
3830.527	26,098.66	σ	5b	
3829.599	26,104.99	π	5b	
3821.113	26,162.96	σ	Ob	
3668.289	27,252.904	σ	5b	
3668.243	27,253.245	π	5	
3667.275	27,260.439	π	7b	
3667.233	27,260.751	σ	7b	
3665.710	27,272.077	π	5b	
3665.666	27,272.404	σ	7b	
3665.019	27,277.219	π	3b	
3664.960	27,277.658	σ	3d	
3662.933	27,292.752	π	3b	
3662.907	27,292.946	σ	4bd	
3660.426	27,311.444	σ	0	
3660.380	27,311.788	π	1d	
3659.725	27,316.676	π	3b	
3659.666	27,317.116	σ	3bd	
3657.690	27,331.873	π	5bd	
3657.630	27,332.322	σ	5b	
3656.432	27,341.276	π	5bd	
3656.390	27,341.591	σ	6b	
3574.361	27,969.043	σ	3b	
3574.301	27,969.513	π	1b	
3530.904	28,313.265	π	8b	
3530.829	28,313.867	σ	8b	
3529.789	28,322.209	π	5d	
3529.723	28,322.738	σ	5b	
3529.421	28,325.162	π	9bb	
3529.287	28,326.227	σ	10bb	

λ(Å) (air)	$\tilde{\nu}$ (cm^{-1}) (vac)	Pol.	I	Remark
3527.333	28,341.928	σ	3	
3527.314	28,342.081	π	2	
3525.542	28,356.326	π	10bbd	
3525.494	28,356.712	σ	10bbd	
3524.499	28,364.717	π	10bb	
3524.450	28,365.111	σ	10bb	
3523.833	28,370.078	π	6bd	
3523.797	28,370.368	σ	6	
3522.668	28,379.460	σ	2	
3522.588	28,380.104	π	0bd	
3393.671	29,458.160	σ	2	
3392.589	29,467.555	π	2b	
3390.762	29,483.432	σ	3b	
3389.570	29,493.800	σ	3	
3379.311	29,583.335	π	00	
3268.278	30,588.334	σ	7	
3268.261	30,588.493	π	8b	
3267.264	30,597.827	σ	8b	
3266.134	30,608.413	σ	8b	
3265.497	30,614.383	σ	5	
3264.521	30,623.536	π	8	
3225.623	30,992.814	σ	00	
3225.269	30,996.216	σ	4	
3224.959	30,999.195	σ	4	
3223.197	31,016.141	σ	5b	
3223.188	31,016.227	π	4	
3222.649	31,021.415	π	00	
3222.560	31,022.271	σ	5b	
3222.017	31,027.499	π	4s	
3220.890	31,038.355	σ	2bd	
3223.519	31,013.042	σ	00	
3178.450	31,452.778	σ	0	
3177.566	31,461.527	π	2bd	
3176.102	31,476.029	π	2bd	
3174.568	31,491.233	π	00	
3031.048	32,982.287	π	4	
3030.678	32,986.314	π	2	
3030.633	32,986.804	σ	8	
3030.412	32,989.209	π	6	
3029.600	32,998.051	π	4b	
3029.397	33,000.262	σ	9b	
3028.575	33,009.218	π	6	
3028.470	33,010.062	σ	2	
3028.150	33,013.851	σ	5	
3007.196	33,243.880	π	00	
3006.312	33,253.655	π	00	
3005.563	33,261.941	σ	5d	
3005.159	33,266.413	π	7	
3004.993	33,268.250	σ	4	
3004.463	33,274.119	σ	00	

λ(Å)(air)	$\tilde{\nu}$ (cm^{-1})(vac)	Pol.	I	Remark
3004.334	33,275.548	π	6	
3003.895	33,280.410	σ	3	
3002.898	33,291.459	σ	7b	
3002.063	33,300.719	σ	7	
3001.215	33,310.128	π	1	
2999.908	33,324.639	σ	5	
2990.205	33,432.771	σ	2bd	
2989.576	33,439.805	π	3s	
2989.560	33,439.984	σ	00	
2989.234	33,443.631	π	3s	
2988.686	33,449.762	σ	4	
2960.661	33,766.377	π	5bb	
2959.284	33,782.088	σ	5b	
2956.730	33,811.268	π	4b	
2956.723	33,811.348	σ	3b	
2955.919	33,820.544	σ	3b	
2955.809	33,821.803	π	00	
2955.094	33,829.986	π	5b	
2941.961		σ	2b	
2940.593		σ	4b	
2939.581		π	4bd	
2939.526		σ	4b	
2938.852		σ	0	
2938.189		σ	1	
2937.568		π	4b	
2936.406		σ	00	
2934.580		π	1	
2933.321		π	0	
2930.483		σ	5b	
2930.221		π	3b	
2929.397		σ	5b	
2929.233		π	4b	
2925.930		π	0	
2923.371		π	0	
2890.110		π	00	
2889.503		π	4b	
2889.100		σ	1	
2888.684		σ	1	
2888.327		π	4	
2887.981		σ	2	
2887.463		σ	4b	
2887.325		π	0	

λ(Å) (air)	$\tilde{\nu}$(cm^{-1}) (vac)	Pol.	I	Remark
2756.327		σ	1	
2756.251		σ	0	
2756.251		π	4	
2655.214		π	0b	
2653.607		π	0b	
2653.167		π	0b	
2652.061		π	1b	
2651.779		σ	0	
2584.614		π	4b	
2583.368		σ	1b	
2580.641		σ	0d	
2579.776		σ	0bd	
2570.921		σ	3	
2569.938		π	5b	
2569.148		σ	2b	
2569.014		π	5b	
2568.461		σ	3bb	

Table 5-2 The empirical energy level scheme for Dy^{3+} in $LaCl_3$

Level		2μ	S_1	$E(cm^{-1})$	I	Pol
$^6H_{15/2}$	Z_1	3	10.08	0.00		
	Z_2	5	5.90	9.82		
	Z_3	3	20.18	9.97		
	Z_4	1	13.84	15.65		
	Z_5	1		40.75		
	Z_6	5		80.48		
	Z_7	3		121.65		
	Z_8	1		140.51		
$^6H_{13/2}$	Y_1	1		3457.03		
	Y_2	1		3490.30		
	Y_3	3		3493.13		
	Y_4	5		3522.31		
	Y_5	1		3546.62		
	Y_6	3		3551.93		
	Y_7	5		3556.60		
$^6H_{11/2}$	X_1	1		5793.28		
	X_2	3		5801.42		
	X_3	5		5842.54		
	X_4	1		5850.29		
	X_5	3		5860.69		
	X_6	5		5864.68		
$^6H_{9/2}$	W_1	5		7592.16		
	W_2	1		7593.59		* 7593.2(σ)
$^6F_{11/2}$	W_3	3		7598.01		* 7598.01(π)
	W_4	3				* 7600.70(π)
	W_5	3		7612.90		
	W_6					* 7660.33(σ)
	W_7					* 7669.52(σ)
	W_8	3		7675.08		* 7675.08(π)
	W_9					* 7690.90(σ)
						* 7692.00(π)
						* 7693.90(σ)
	W_{10}	5				* 7698.97(σ)
	W_{11}			7746.50		
						* 7766.50(σ)
$^6H_{7/1}$	A_1			8937.16		
	A_2			8944.40		

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* Varsanyi, Dieke, J.Chem.Phys. 36, 835 (1962)

Level		2μ	S_1	$E(cm^{-1})$	I	Pol
$^6F_{9/2}$	A_3	5		8952.14		σ
	A_4					
	A_5	5		8975.06		
	A_6	1		8981.14	9	σ
	A_7	3		8999.32	9d	π
	A_8	3		9011.78	9d	π
	A_9	5		9091.57		σ
$^6H_{5/2}$	B_1	5		10124.48		
	B_2	3		10151.57		
	B_3	1				
$^6F_{7/2}$	C_1	3	4.21	10913.36	10	π
	C_2	5	8.79	10917.16	7d	σ
	C_3	1	1.05	10922.23	5	σ
	C_4	5	5.10	10949.45	9d	σ
$^6F_{5/2}$	D_1	1	1.46	12315.60	10	σ
	D_2	5	6.36	12317.87	10	σ
	D_3	3	3.84	12336.08	9	π
$^6F_{3/2}$	E_1	3	3.14	13114.47	10	π
	E_2	1	1.00	13116.84	9	σ
$^6F_{1/2}$		1				
$^4F_{9/2}$	F_1	5		20963.31		
	F_2			21066.91		
	F_3			21097.18		
	F_4					
	F_5					
	F_6					
$^4I_{15/1}$	G_1			21954.07		
	G_2			22174.42		
	G_3			22175.47		
	G_4			22193.12		
	G_5			22207.49		
	G_6			22226.41		
	G_7			22247.30		
	G_8					
$^4G_{11/2}$	H_1	3		23215.12	3	π
	H_2			23302.76	8	σ
	H_3	3		23337.65	5d	π
	H_4			23352.22	1d	σ
	H_5			23367.68	3d	σ
	H_6	3		23375.02	4d	π
	H_7	3		23379.79	7	π

Level		2μ	S_1	E(cm^{-1})	I	Pol	
$^4M_{21/2}$	I_1	3		24938.52	4dd	π	#
	I_2	5		24938.85	9	σ	
	I_3	1		24944.62	7d	σ	
	I_4	1		24945.66	1d	σ	
	I_5	1		24949.52	0d	σ	
	I_6	3		24976.51	0d	π	
	I_7	5or1		24980.07	00d	σ	
	I_8						
$^4I_{13/2}+^4F_{3/2}$	J_1			25571.32	1	$\sigma\pi$	
	J_2			25606.68	1	$\sigma\pi$	*
$+^4I_{17/2}$	J_3	3		25616.11	9	π	
	J_4	5		25621.91	9	σ	
	J_5			25622.68	3	$\sigma\pi$	
	J_6	3		25635.87	9	π	
	J_7			25653.04	4	σ	
	J_8	3		25686.16	3dd	π	
	J_9			25701.21	1dd	$\sigma\pi$	
	J_{10}			25702.63	5dd	σ	
	J_{11}			25709.79	2dd	σ	
$^4M_{19/2}$	K_1			26089.14	6dd	$\sigma\pi$	*
	K_2	1		26098.72	7dd	σ	
	K_3			26100.58	1dd	π	*
	K_4	3		26104.99	9dd	π	
	K_5	1		26116.05	2dd	σ	
	K_6			26163.35	4dd	σ	
	K_7			26196.28	1dd	σ	+

The $^{2S+1}L_J$ symbols of levels I, J and K are given by W. T. Carnall, Hannah Crosswhite and H. Crosswhite, " Energy level structure and transition probabilities of the trivalent lanthanides in LaF_3 " (Argonne National Laboratory ANL-78-XX-95).

* means T-induced lines.

\+ Upto here the main part of the data was presented in G. H. Dieke's book (Ref.1).

** For energy levels $^6H_{15/2}$ to $^6F_{3/2}$, the energy has been reported by J. D. Axe and G. H. Dieke, " Calculation of crystal-field splittings of Sm^{+3} and Dy^{+3} levels in $LaCl_3$ with inclusion of J mixing ", J. Chem. Phys., 36, 835 (1962).

Level	2μ	S_1	$E(cm^{-1})$	I	Pol	
$^4P_{3/2}+^6P_{5/2}$	L		27252.9	5b	σ	*
			27253.3	5	π	
			27260.4	7b	π	# 27260.4 ($\sigma\pi$)
			27260.8	7b	σ	
			27272.1	5b	π	
			27272.4	7b	σ	
			27277.2	3b	π	
			27277.7	3d	σ	
						+ 27289.7 (π)
						+ 27291.4 (π)
			27292.8	3b	π	
			27293.0	4bd	σ	
			27311.4	0	σ	
			27311.8	1d	π	
			27316.7	3b	π	
			27317.1	3bd	σ	
			27331.9	5bd	π	
			27332.3	5b	σ	
			27341.3	5bd	π	
			27341.6	6b	σ	
$^4I_{11/2}$	M					+ 27827.1 (σ)
			27969.0	3b	σ	
			27969.5	1b	π	
$^4M_{15/2}+^6P_{7/2}$	N		28313.3	8b	π	
			28313.9	8b	σ	
			28322.2	5d	π	
			28322.7	5b	σ	
			28325.2	9bb	π	
			28326.2	10bb	σ	# 28326.2 (σ)
			28341.9	3	σ	
			28342.1	2	π	
			28356.3	10bbbd	π	
			28356.7	10bbbd	σ	
			28364.7	10bb	π	
			28365.1	10bb	σ	
			28370.1	6bd	π	
			28370.4	6	σ	
			28379.5	2	σ	
			28380.1	0bd	π	

---

* From here on the data are new results. But there were 20 lines recorded between 27250 and 36300 cm^{-1} in CD's paper (Ref. 3). The common lines are marked by "#" and others are marked by "+".

Level		2μ	S_1	$E(cm^{-1})$	I	Pol	
$^4F_{5/2}+^4I_{9/2}$	O			29458.2	2	σ	
				29467.6	2b	π	# 29467.8(π)
							+ 29481.6(σ)
				29483.4	3b	σ	
							+ 29489.9
				29493.8	3	σ	
				29583.3	00	π	
$^4G_{9/2}+^4M_{17/2}$	P						+29866.96(σ)
$^6P_{3/2}$	Q						+ 30583.3(σ)
				30588.3	7	σ	
				30588.5	8b	σ	
				30597.8	8b	σ	
				30608.4	8b	σ	
				30614.4	5	σ	
				30623.5	8	π	
$^4K_{15/2}$ +	R			30996.2	4	σ	# 30996.5(σ)
				30999.2	4	σ	
$^{2,4}L_{19/2}$ +				31016.1	5b	σ	
				31016.2	4	π	
$^4M_{19/2}$				31021.4	00	π	
				31022.3	5b	σ	
				31027.5	4s	π	
				31038.4	2bd	σ	
$^4G_{7/2}$	S	3		31452.8	0	σ	
				31461.5	2bd	π	# 31462.3(π)
				31476.0	2bd	π	
				31491.2	00	π	
$^4K_{13/2}$	T			32978.1		π	+ 32978.1(π)
				32982.3	4	π	
				32986.3	2	π	
				32986.8	8	σ	
				32989.2	6	π	
							+ 32992.8(σ)
				32998.1	4b	π	
				33000.3	9b	σ	
				33009.2	6	π	
				33010.1	2	σ	
				33013.9	5	σ	
$^4H_{13/2}$	U			33261.9	5d	σ	# 33262.4(σ)
		3		33266.4	7	π	
				33268.3	4	σ	
		3		33275.6	6	π	
				33280.4	3	σ	
				33291.5	7b	σ	
				33300.7	7	σ	
		3		33310.1	1	π	
				33324.6	5	σ	

Level		2μ	S_1	$E(cm^{-1})$	I	Pol	
$^4F_{3/2}$	V			33432.8	2bd	σ	
				33439.8	3s	π	
		3		33443.9		π	# 33443.9(π)
				33449.8	4	σ	
$^4F_{3/2}$	W			33766.4	5bb	π	
				33782.1	5b	σ	# 33781.5
$^4D_{7/2}+^4H_{11/2}$ + $^4L_{17/2}+^4H_{9/2}$				33811.3	4b	σ	
				33811.4	3b	σ	
				33820.5	5b	σ	
				33821.8	00	π	
				33830.0			
				33983.9		σ	
				33997.1		σ	
				34007.8		π	
				34009.3		σ	
				34032.0		π	
				34113.6		σ	
				34117.2		π	
				34126.1		σ	
				34128.8		π	
				34168.4		π	
$^4G_{11/2}+^4H_{11/2}$	X			34598.5		π	# 34600.2
				34603.7		σ	
				34607.5		σ	
				34612.1		π	
				34615.8		σ	
				34622.0		σ	
$^4K_{11/2}$	Y						+ 35744.5(σ)
$^4L_{13/2}+^4G_{5/2}$ + $^4L_{13/2}$	Z	3		35278.4		π	# 35279.4
$^4G_{9/2}+^4G_{7/2}$ + $^4P_{1/2}$		3		37695.3		π	
$^4F_{5/2}+^2L_{15/2}$ + $^4F_{3/2}$		3		38677.1		π	
				38695.8		σ	
				38733.1		σ	
				38774.1		σ	
$^4P_{5/2}+^4P_{3/2}$				38882.7		σ	
		3		38899.4		π	
		3		38907.2		π	
				38912.9		σ	
				38923.1		σ	

Table 5-3 The centers of gravity of energy levels of $Dy^{3+}:LaF_3$

Level	E (cm^{-1})
$^6H_{15/2}$	175
$^6H_{13/2}$	3625
$^6H_{11/2}$	5952
$^6H_{9/2}$	7806
$^6F_{11/2}$	7853
$^6F_{9/2}$	9166
$^6H_{7/2}$	9223
$^6H_{5/2}$	10273
$^6F_{7/2}$	11070
$^6F_{5/2}$	12471
$^6F_{3/2}$	13267
$^6F_{1/2}$	13814
$^4F_{9/2}$	21228
$^4H_{15/2}$	22222
$^4G_{11/2}$	23563
$^4M_{21/2}$	25109
$^4I_{13/2}$	25794
$^4F_{7/2}$	25856
$^4K_{17/2}$	25890
$^4M_{19/2}$	26334
$^6P_{3/2}$	27543
$^6P_{5/2}$	27624

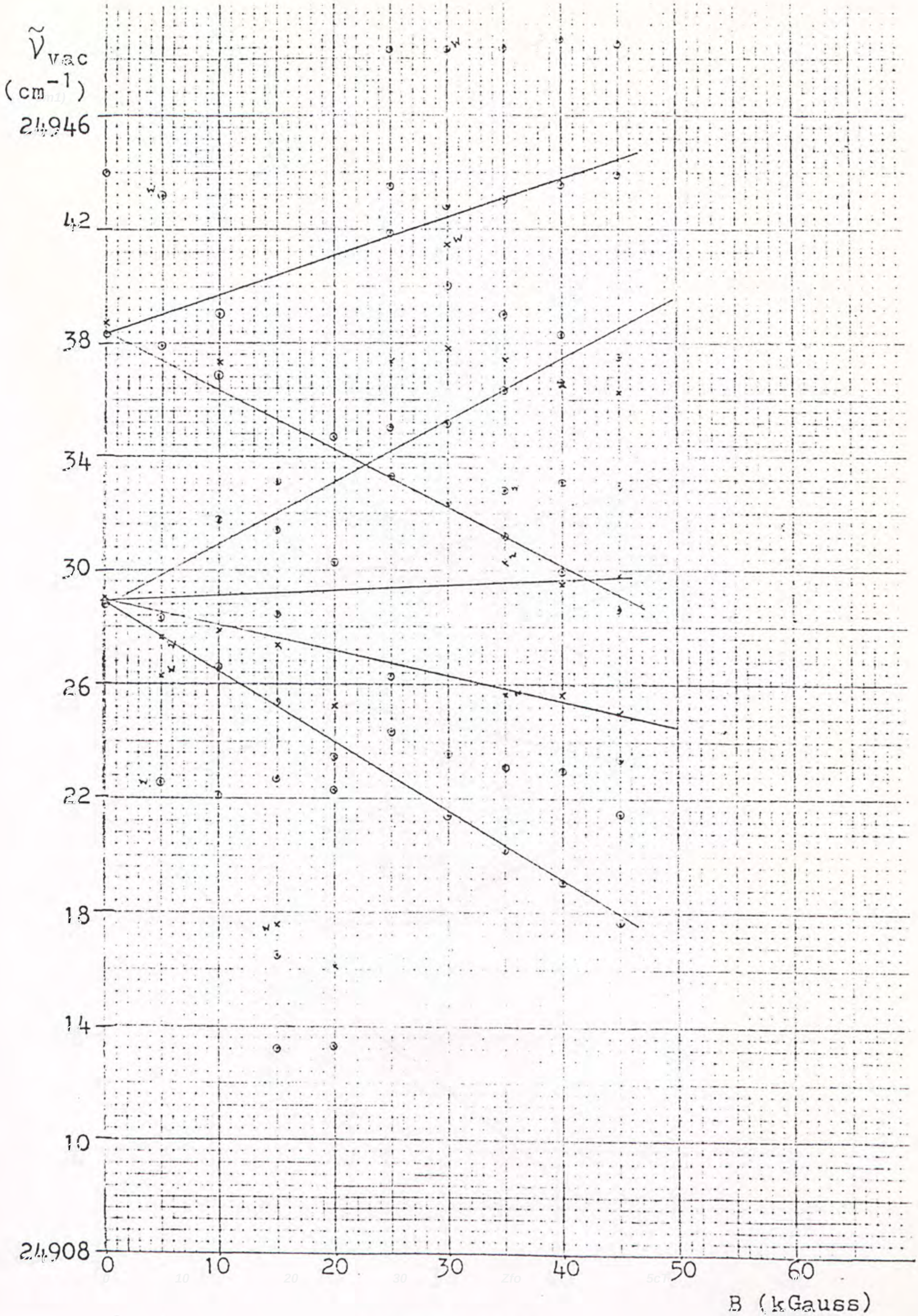

$\tilde{\nu}_{vac}$ (cm^{-1})
24946
42
38
34
30
26
22
18
14
10
24908
0
10
20
30
40
50
60
B (kGauss)

Figure 5-2(a)

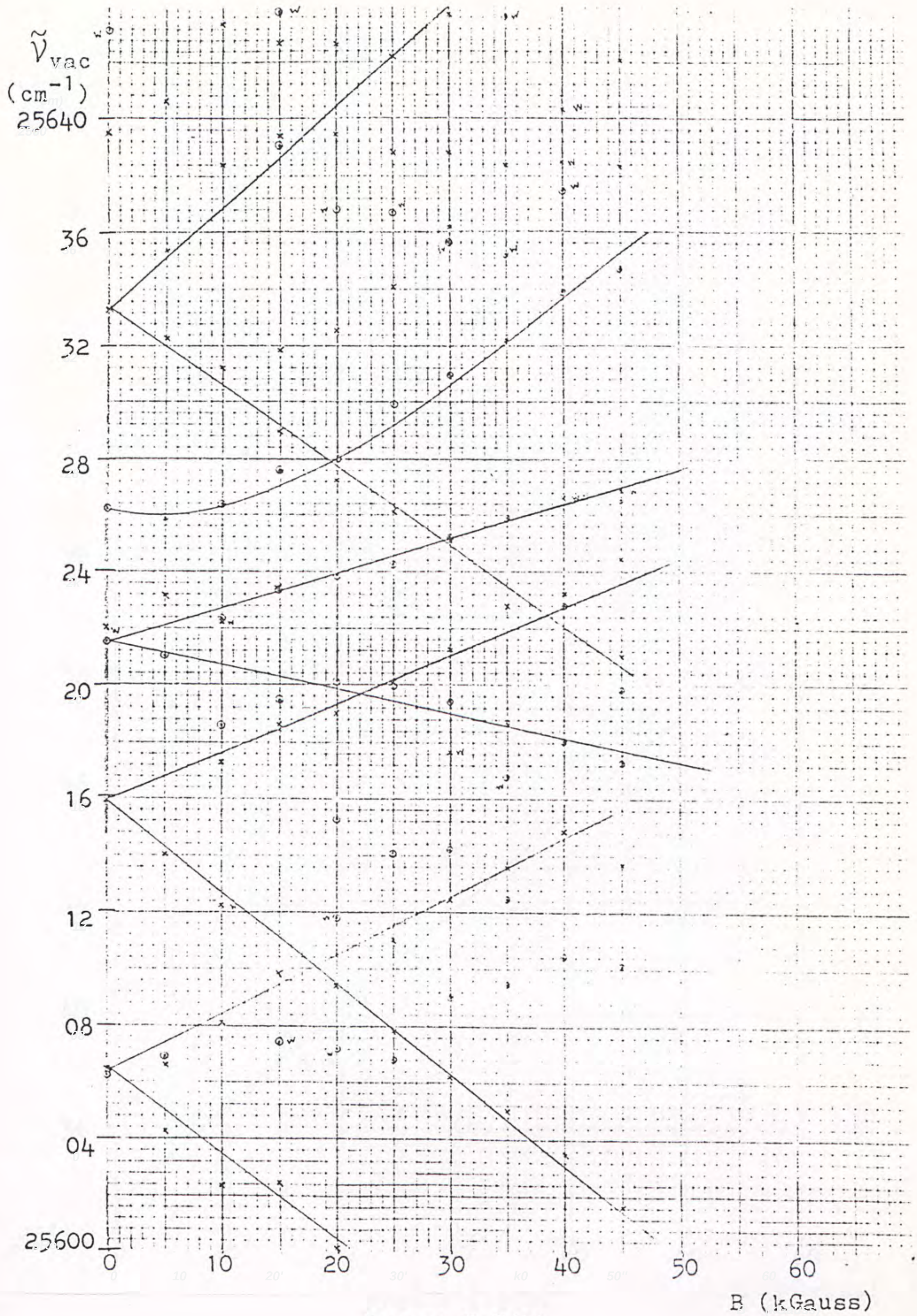

$\tilde{\nu}_{vac}$
(cm^{-1})
25640
36
32
28
24
20
16
12
08
04
25600
0
10
20
30
40
50
60
B (kGauss)

Figure 5-2(b)

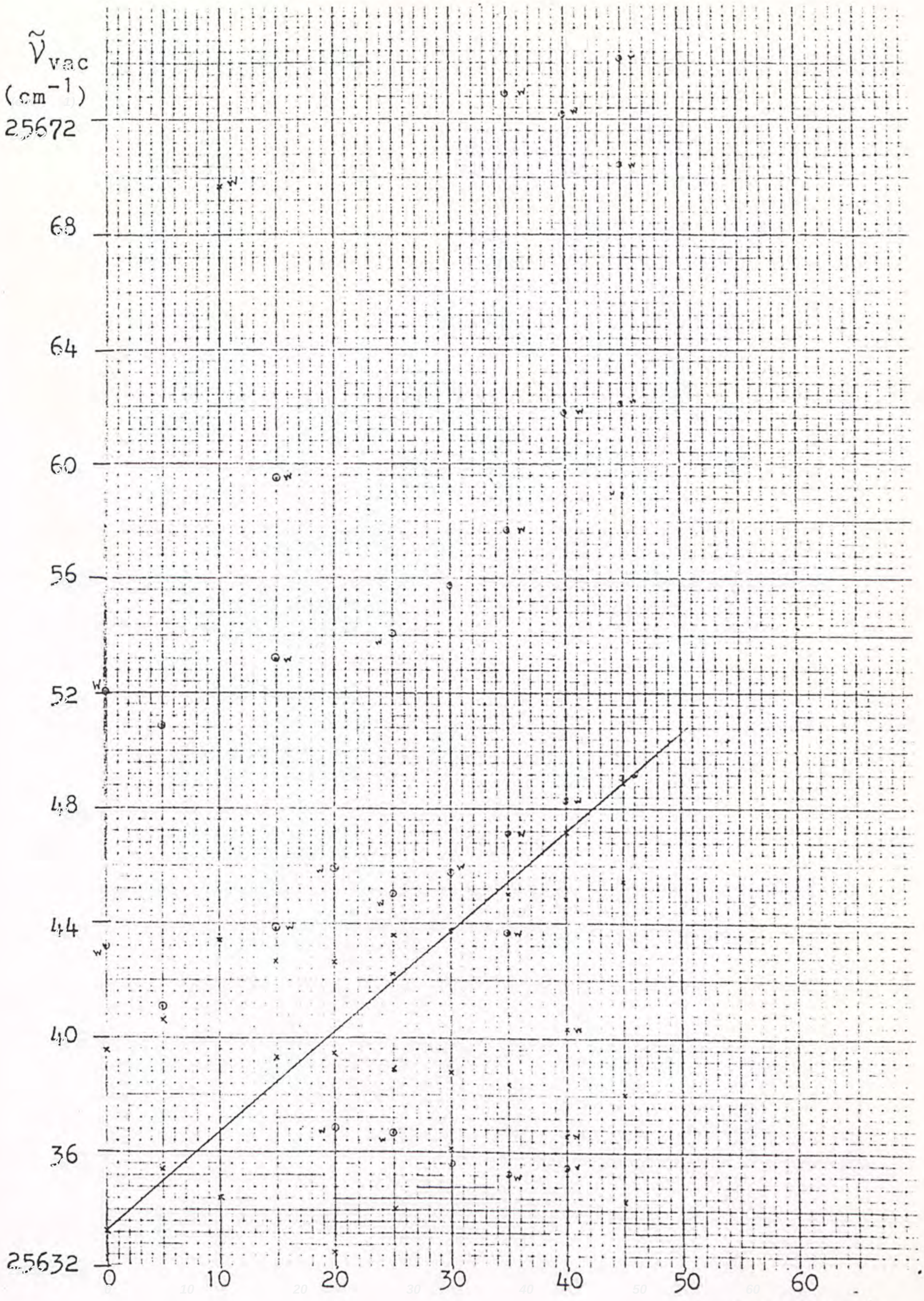
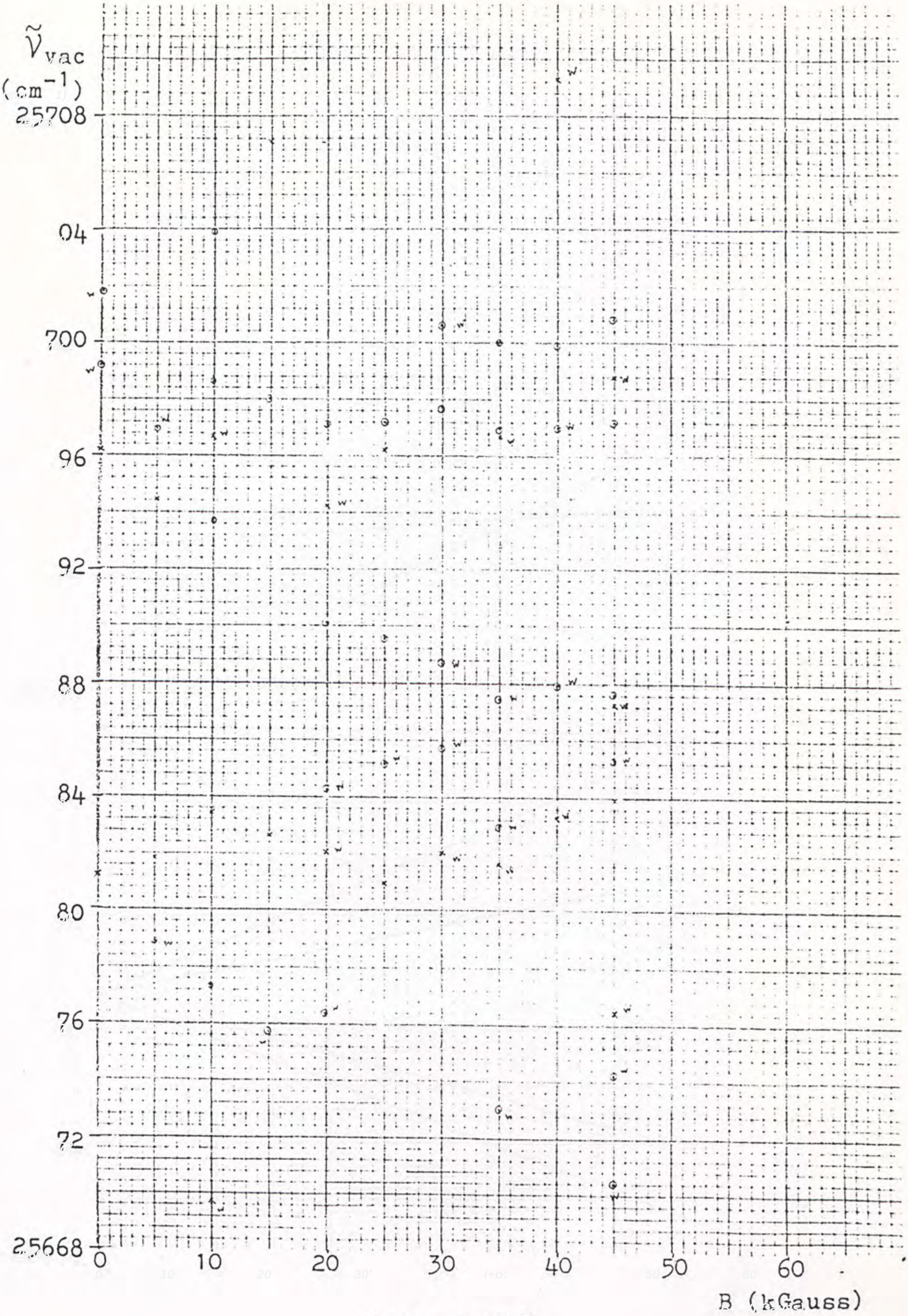

$\tilde{\nu}_{vac}$
(cm^{-1})
25672
68
64
60
56
52
48
44
40
36
25632
0
10
20
30
40
50
60
B (kGauss)

Figure 5-2(c)



$\tilde{\nu}_{vac}$ (cm^{-1})
25708
04
700
96
92
88
84
80
76
72
25668
0
10
20
30
40
50
60
B (kGauss)

Figure 5-2(d)

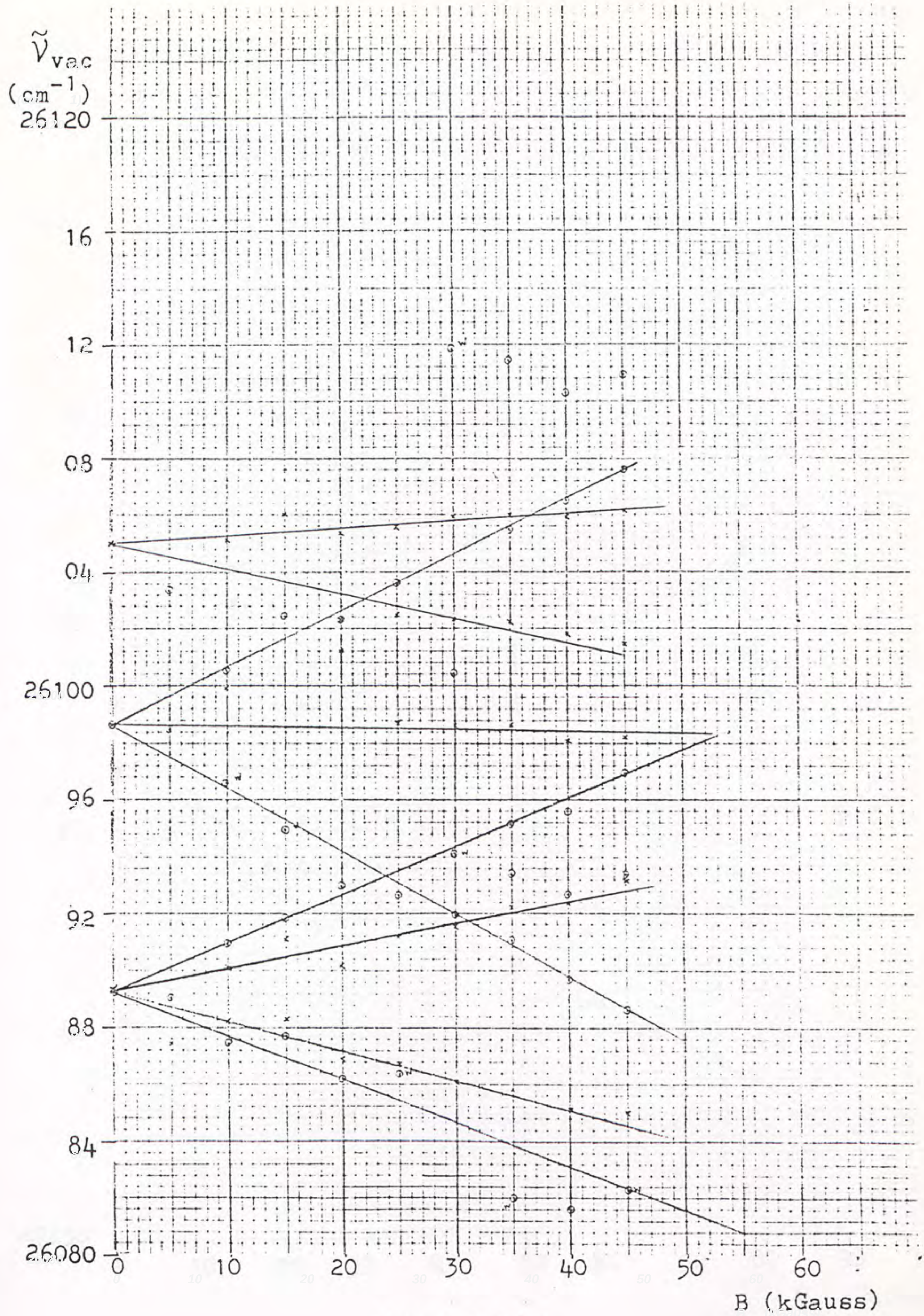
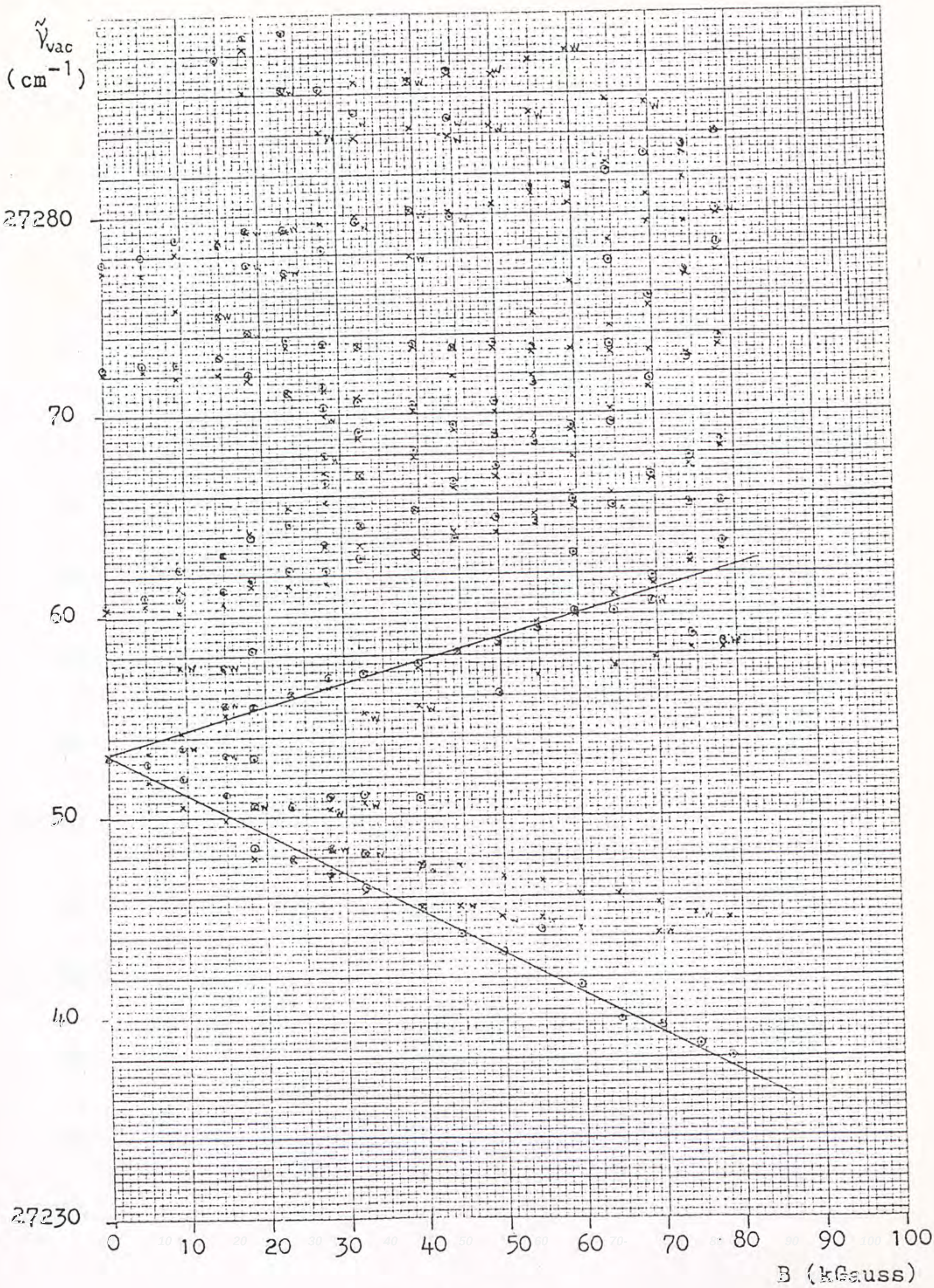
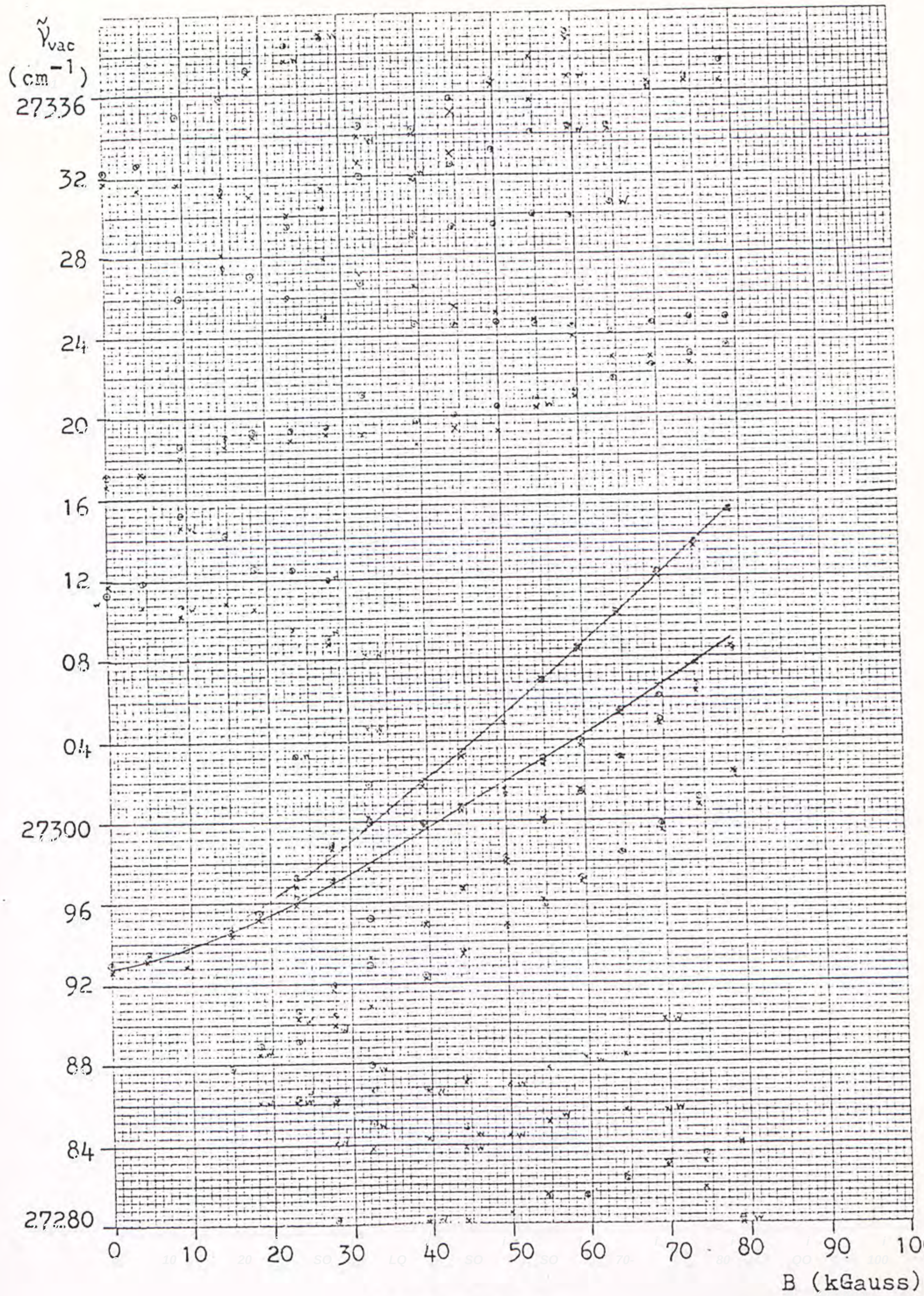

$\tilde{\nu}_{vac}$
(cm^{-1})
26120
16
12
08
04
26100
96
92
88
84
26080
0
10
20
30
40
50
60
B (kGauss)

Figure 5-2(e)



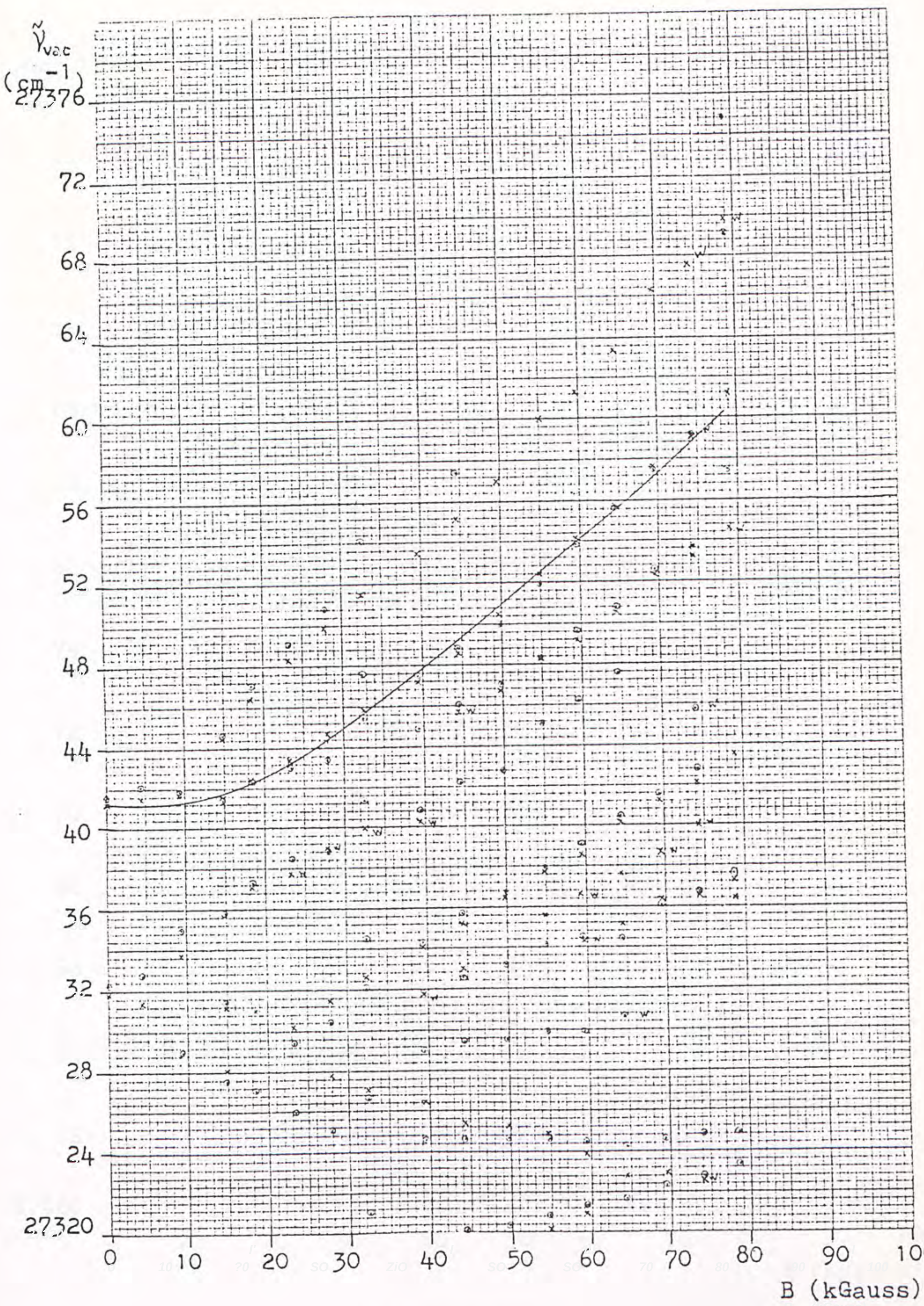
$\tilde{\nu}_{vac}$ (cm^{-1})
27280
70
60
50
40
27230
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(f)



$\tilde{\nu}_{vac}$
(cm^{-1})
27336
32
28
24
20
16
12
08
04
27300
96
92
88
84
27280
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(g)



$\tilde{\nu}_{vac}$ (cm^{-1})
27376
72
68
64
60
56
52
48
44
40
36
32
28
24
27320
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(h)

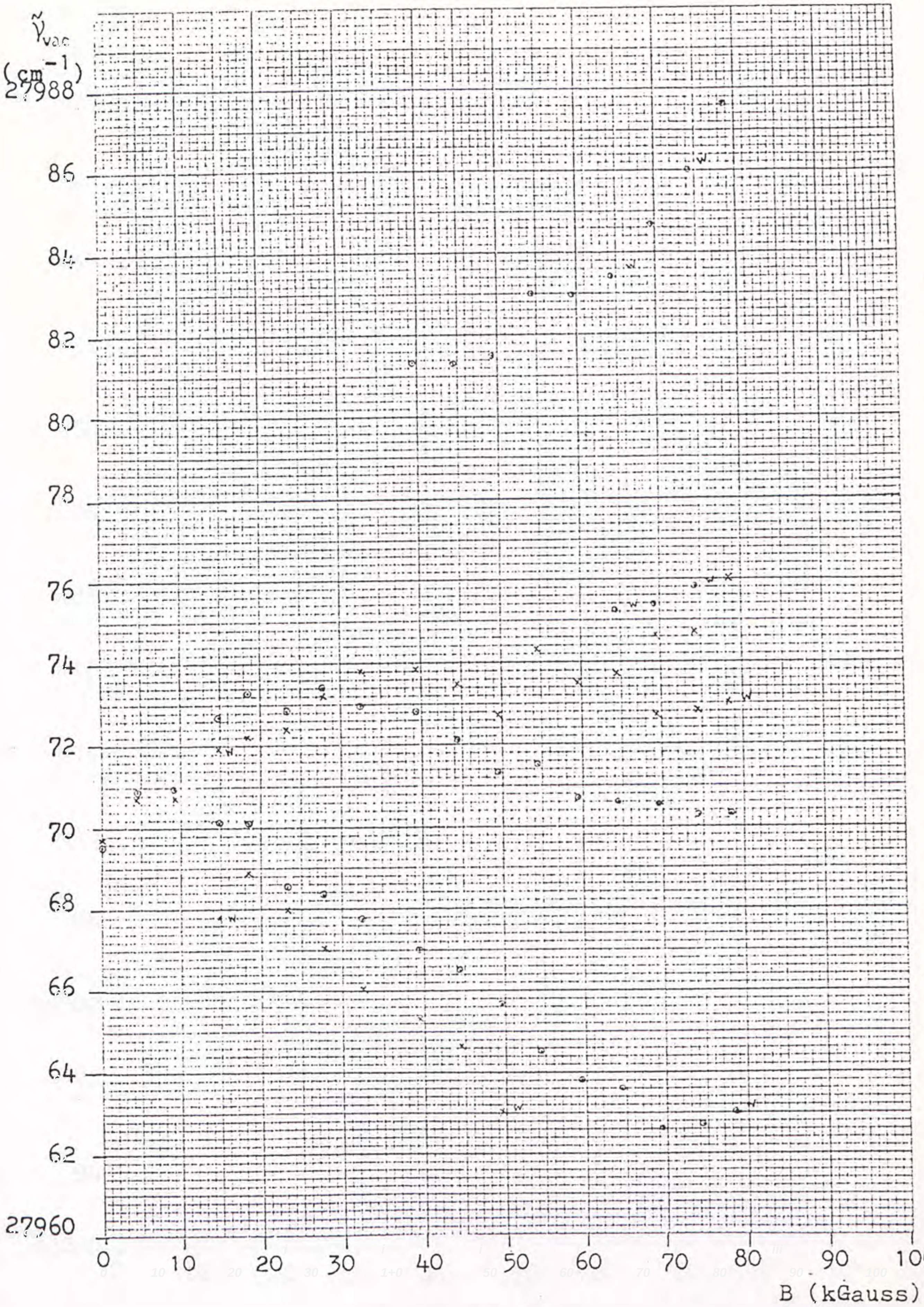
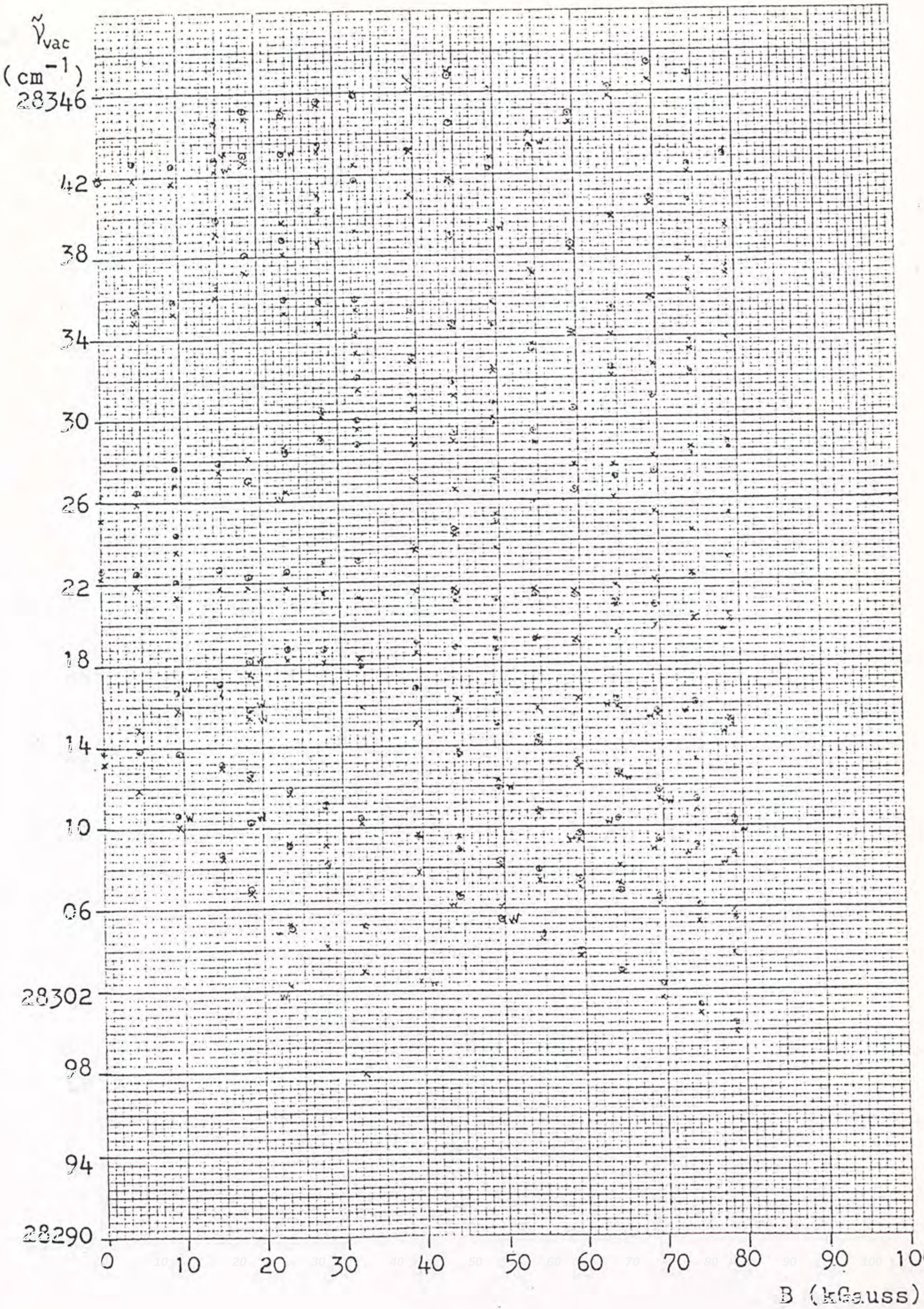
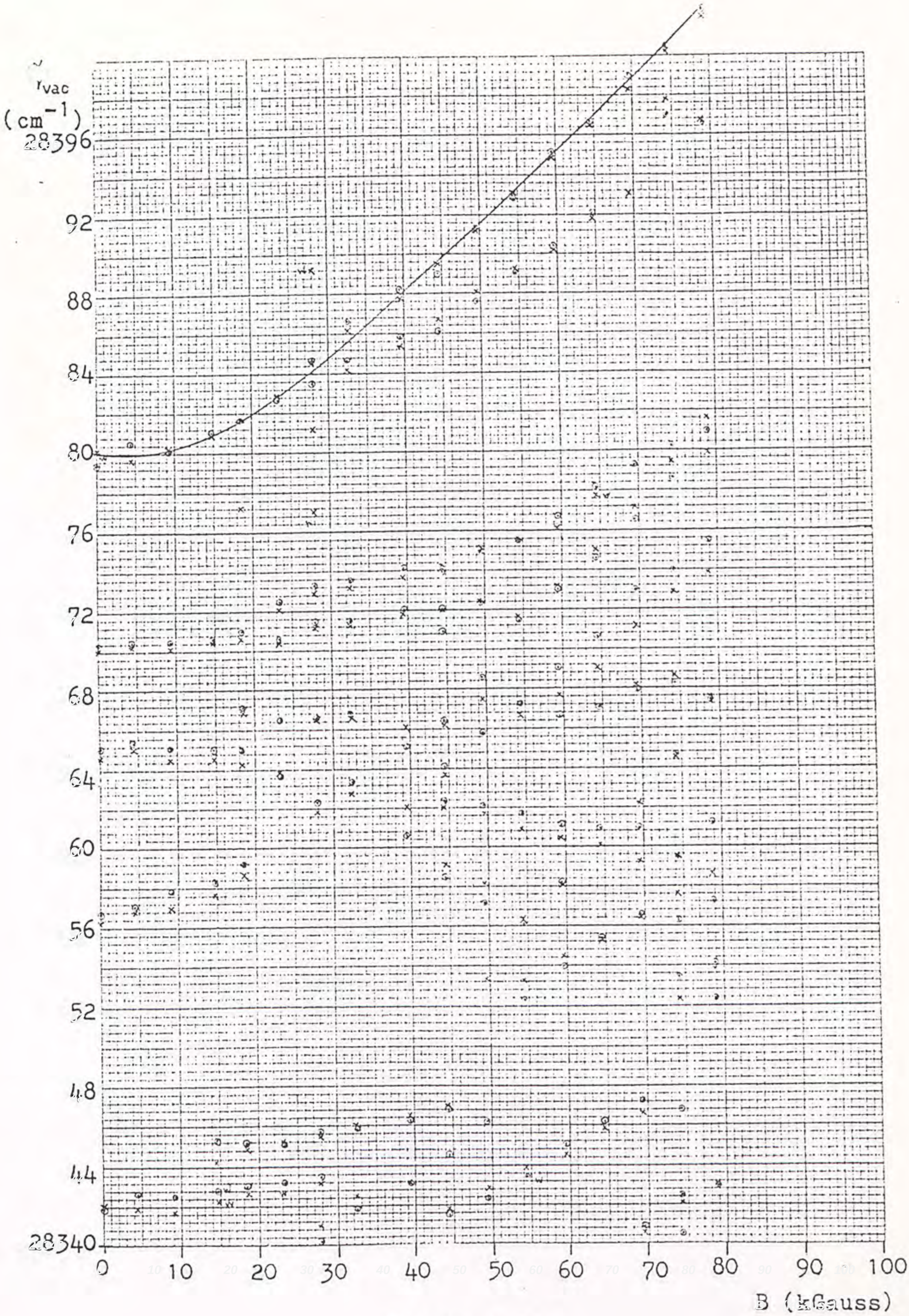

$\tilde{\nu}_{vac}$ (cm^{-1})
27988
86
84
82
80
78
76
74
72
70
68
66
64
62
27960
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(i)



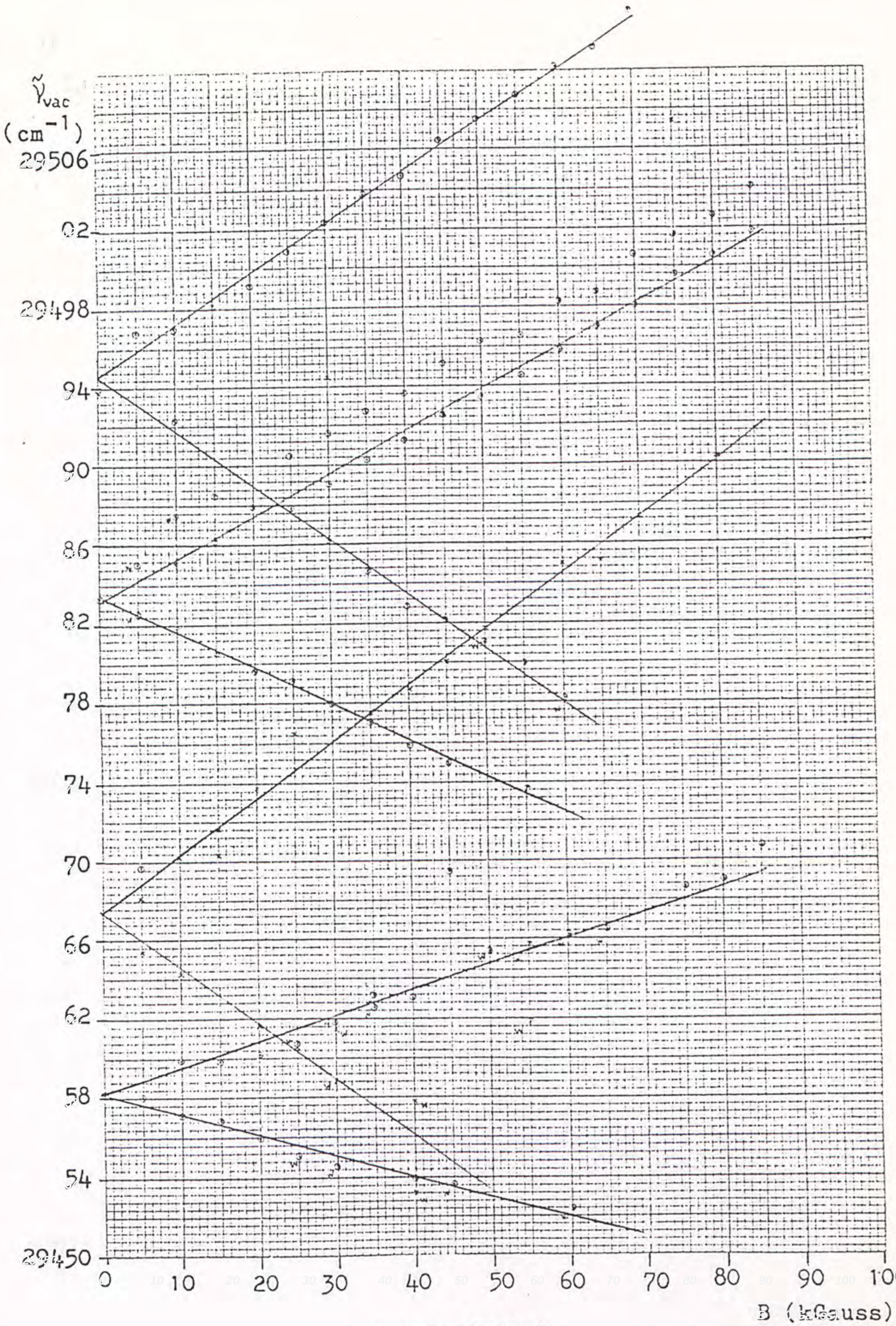
$\tilde{\gamma}_{vac}$ (cm^{-1})
28346
42
38
34
30
26
22
18
14
10
06
28302
98
94
28290
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(j)



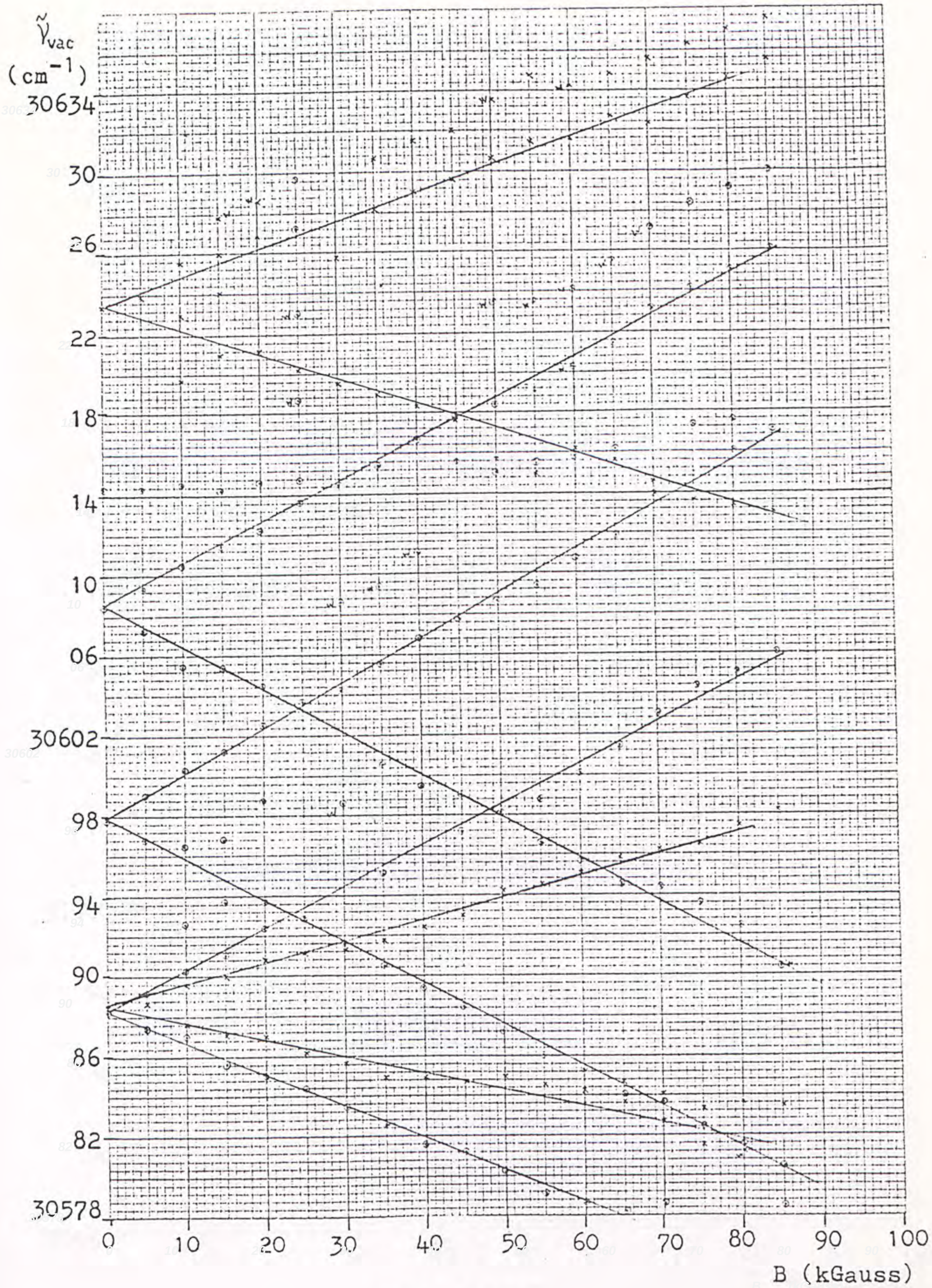
$\tilde{\nu}_{vac}$
(cm^{-1})
28396
92
88
84
80
76
72
68
64
60
56
52
48
44
28340
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(1)



$\tilde{\gamma}_{vac}$ (cm^{-1})
29506
02
29498
94
90
86
82
78
74
70
66
62
58
54
29450
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(m)



$\tilde{\gamma}_{vac}$
(cm^{-1})
30634
30
26
22
18
14
10
06
30602
98
94
90
86
82
30578
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(n)

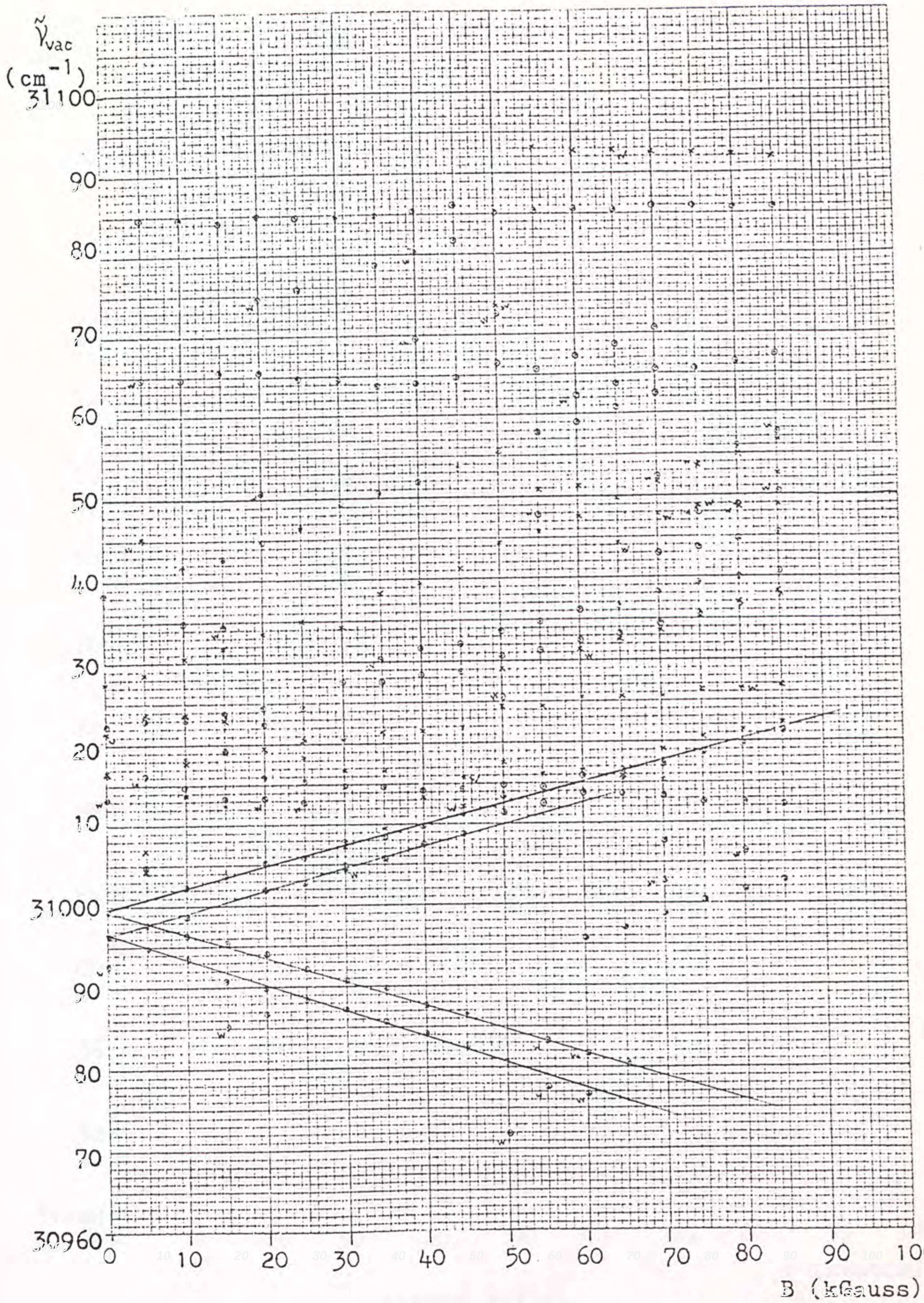

$\tilde{\gamma}_{vac}$ (cm^{-1})
31100
90
80
70
60
50
40
30
20
10
31000
90
80
70
30960
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(o)

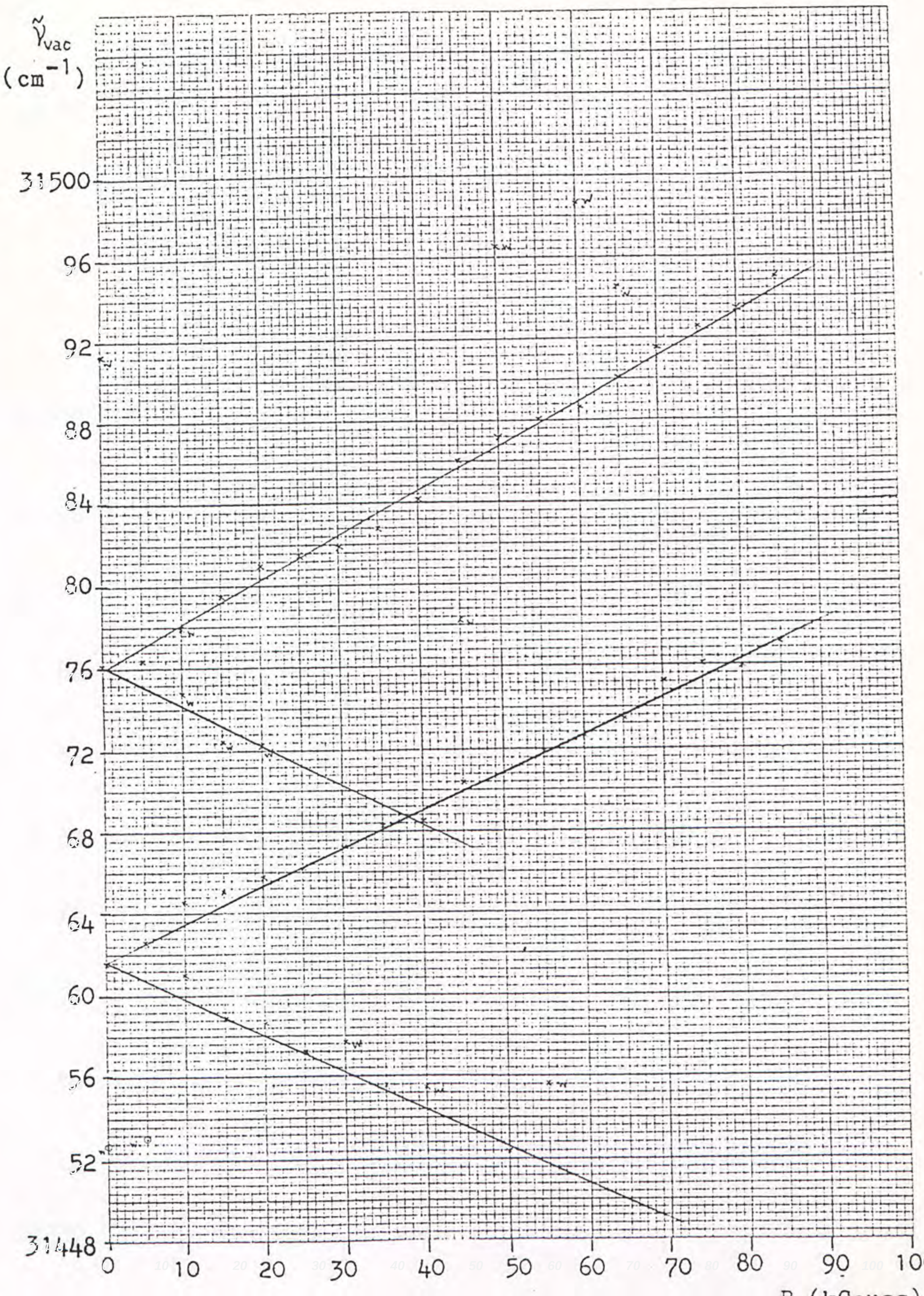

$\tilde{\nu}_{vac}$
(cm^{-1})
31500
96
92
88
84
80
76
72
68
64
60
56
52
31448
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(p)

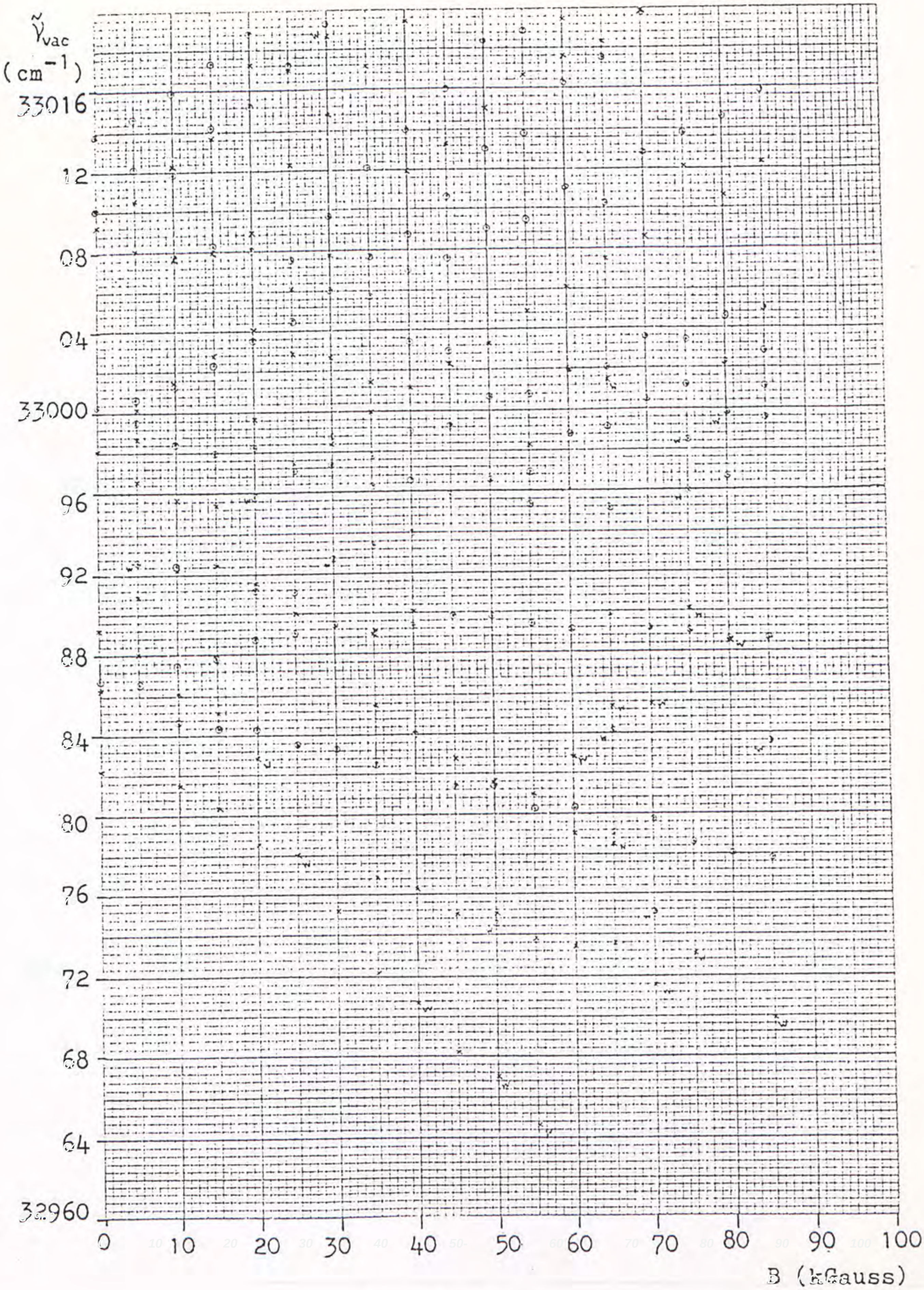

$\tilde{\nu}_{vac}$
(cm^{-1})
33016
12
08
04
33000
96
92
88
84
80
76
72
68
64
32960
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(q)

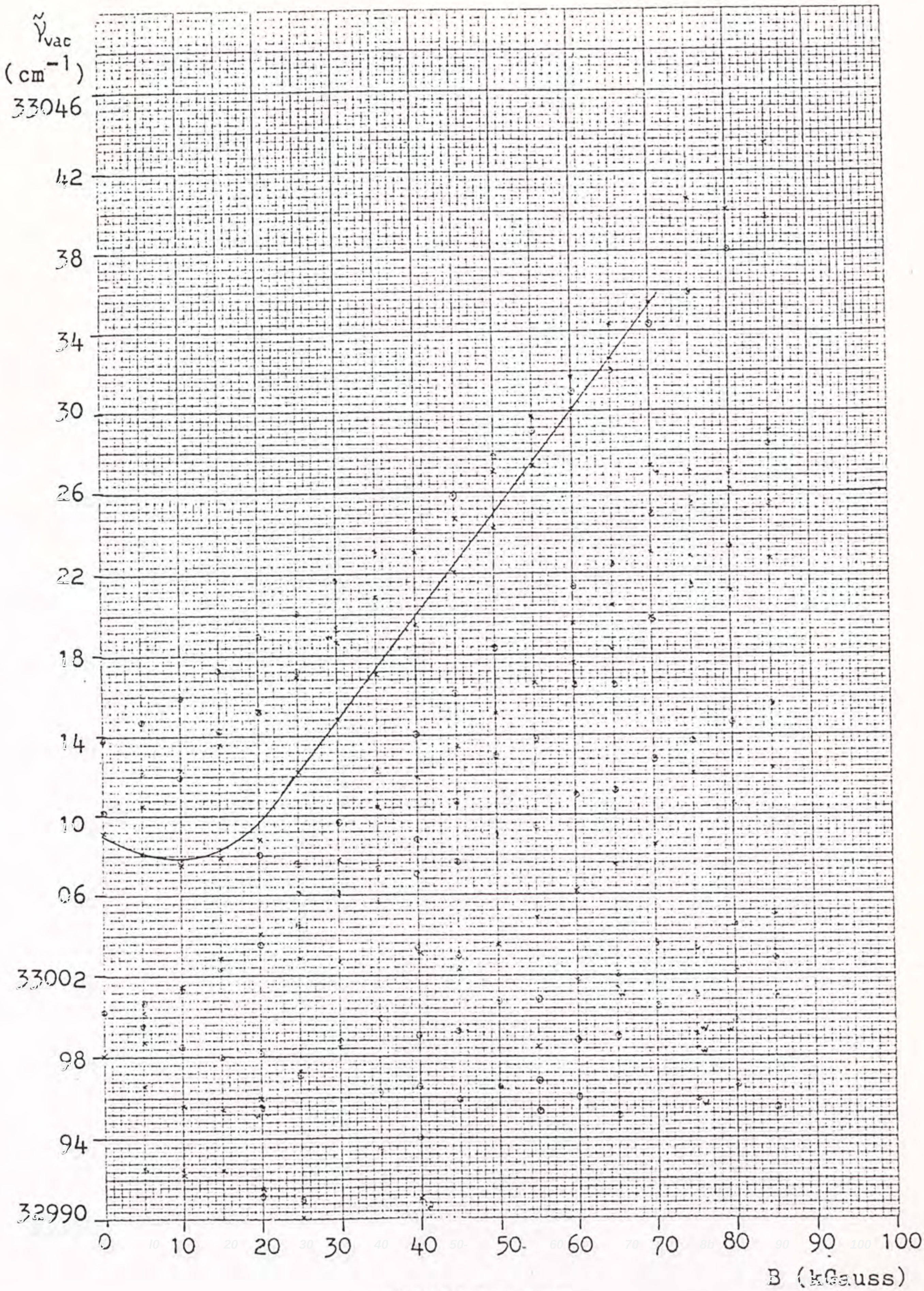
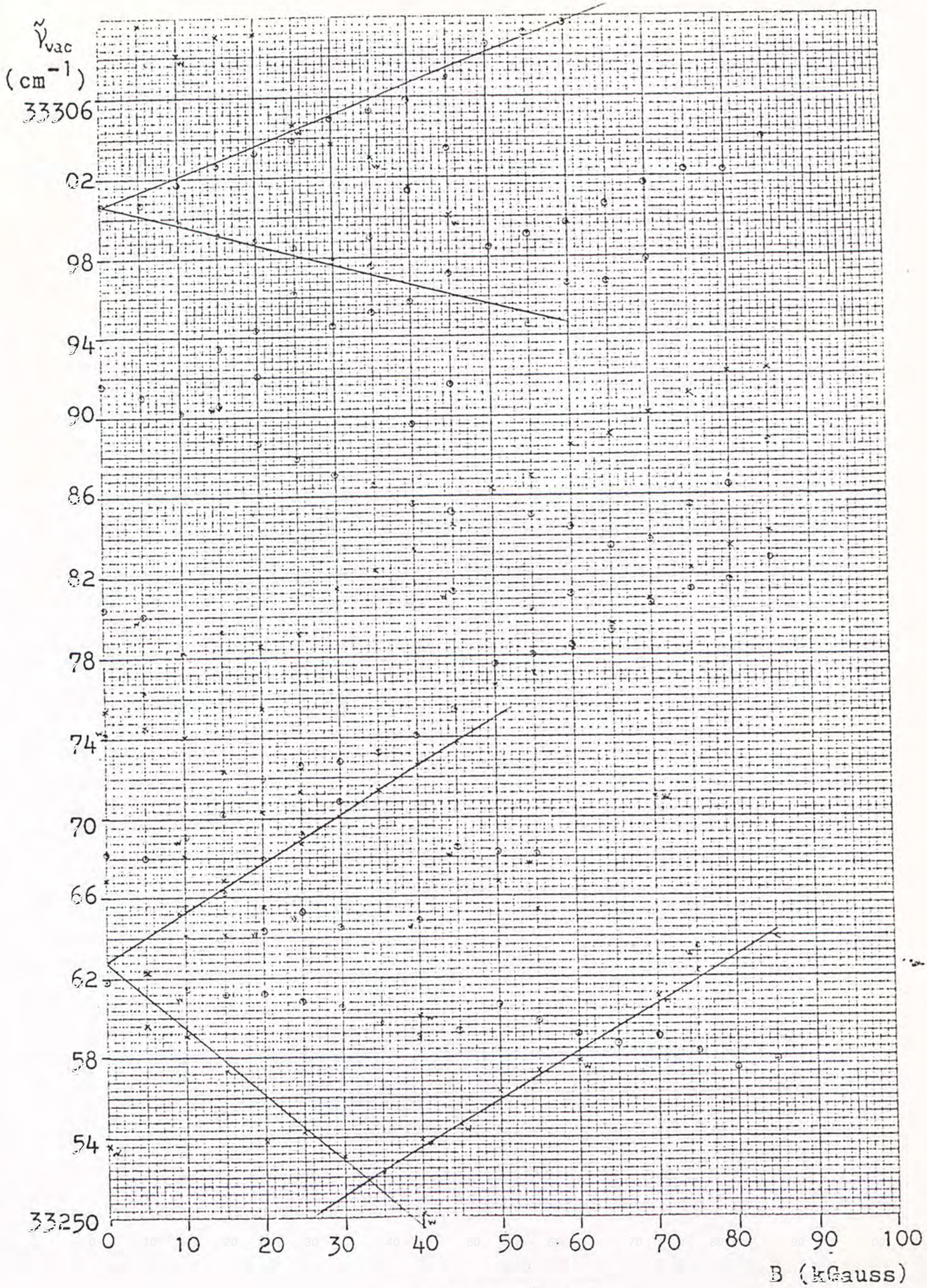
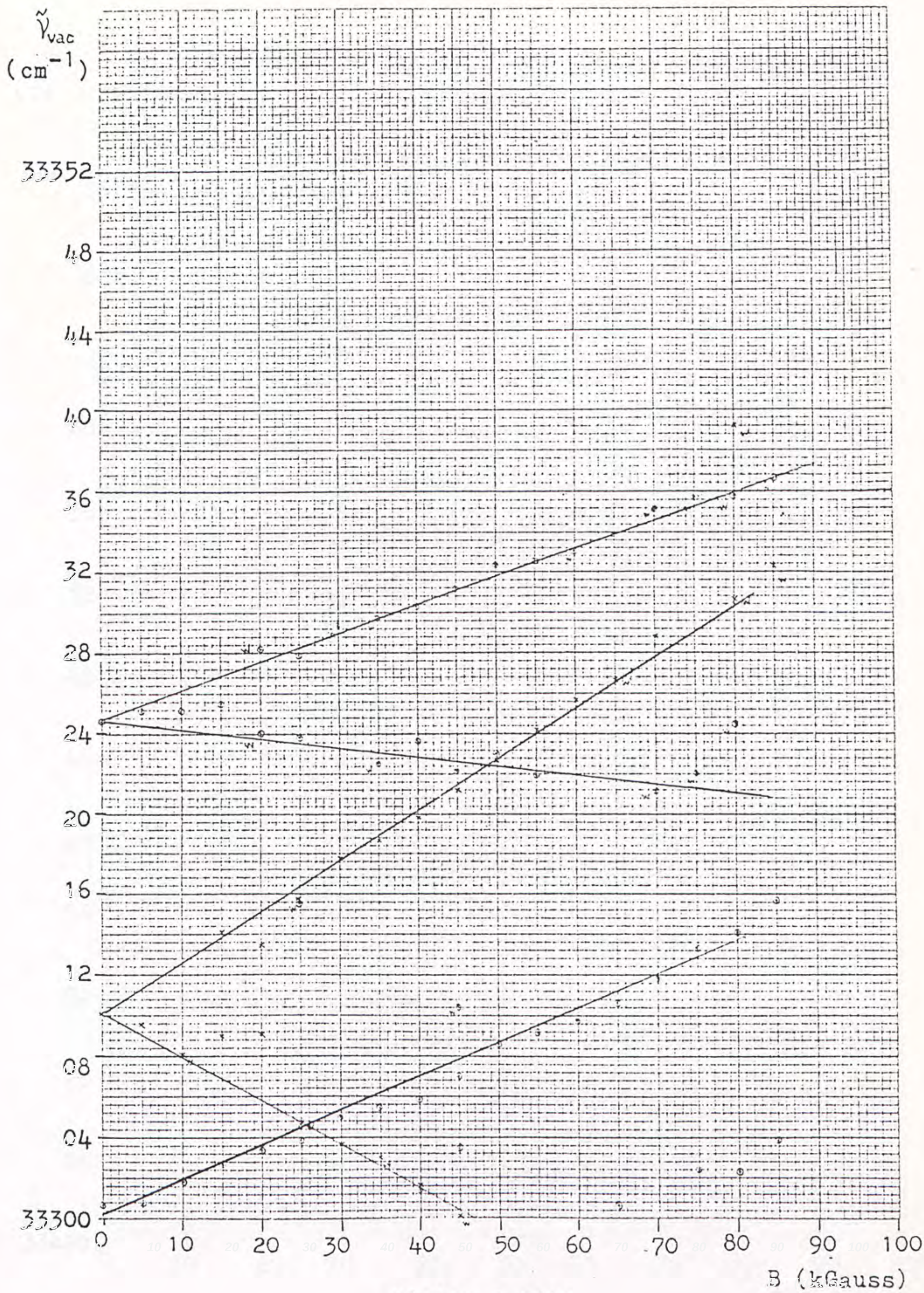

$\tilde{\gamma}_{vac}$
(cm^{-1})
33046
42
38
34
30
26
22
18
14
10
06
33002
98
94
32990
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(r)



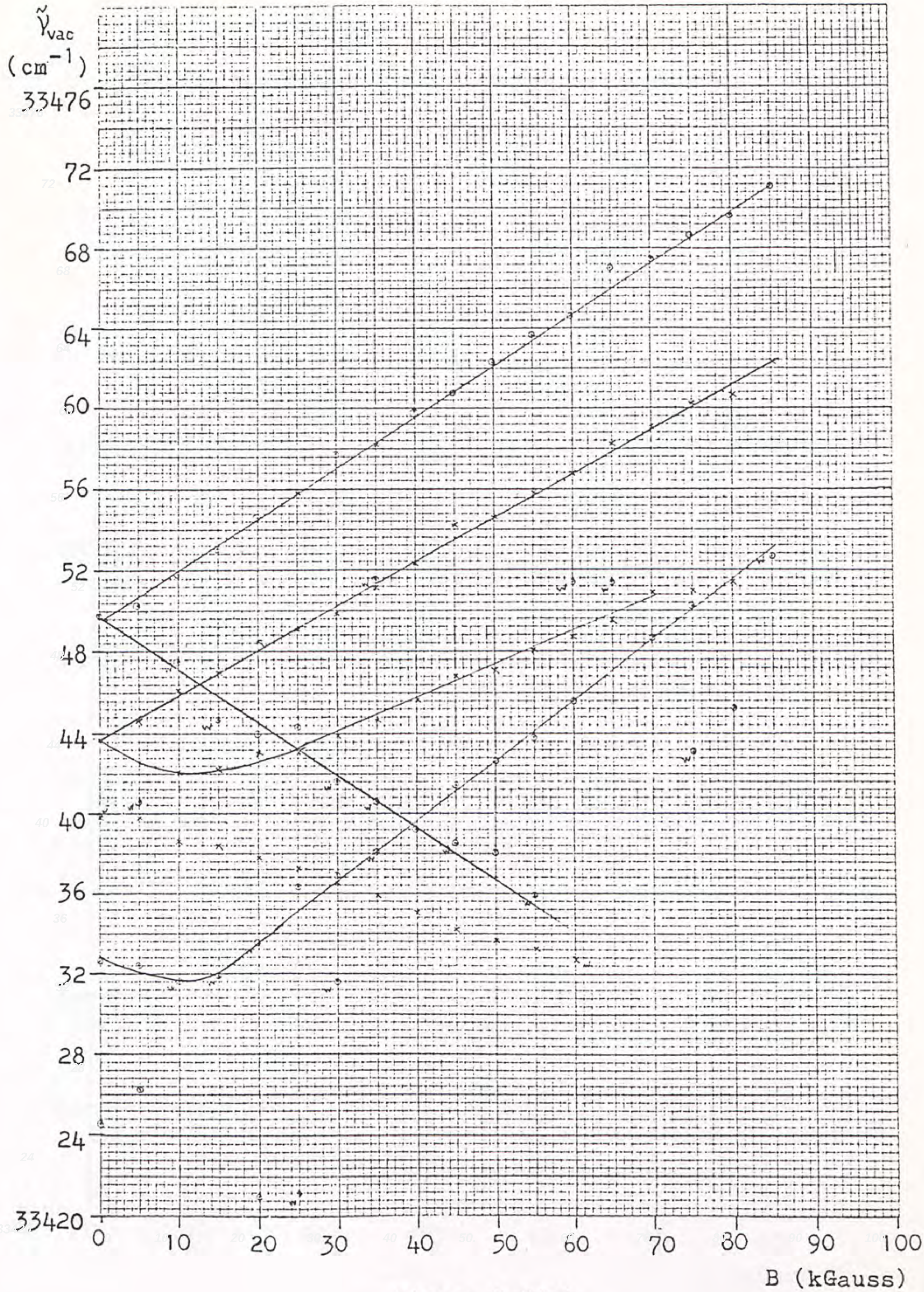
$\tilde{\nu}_{vac}$
(cm^{-1})
33306
02
98
94
90
86
82
78
74
70
66
62
58
54
33250
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(s)



$\tilde{\nu}_{vac}$ (cm^{-1})
33352
48
44
40
36
32
28
24
20
16
12
08
04
33300
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(t)



$\tilde{\nu}_{vac}$ (cm^{-1})
33476
72
68
64
60
56
52
48
44
40
36
32
28
24
33420
0
10
20
30
40
50
60
70
80
90
100
B (kGauss)

Figure 5-2(u)

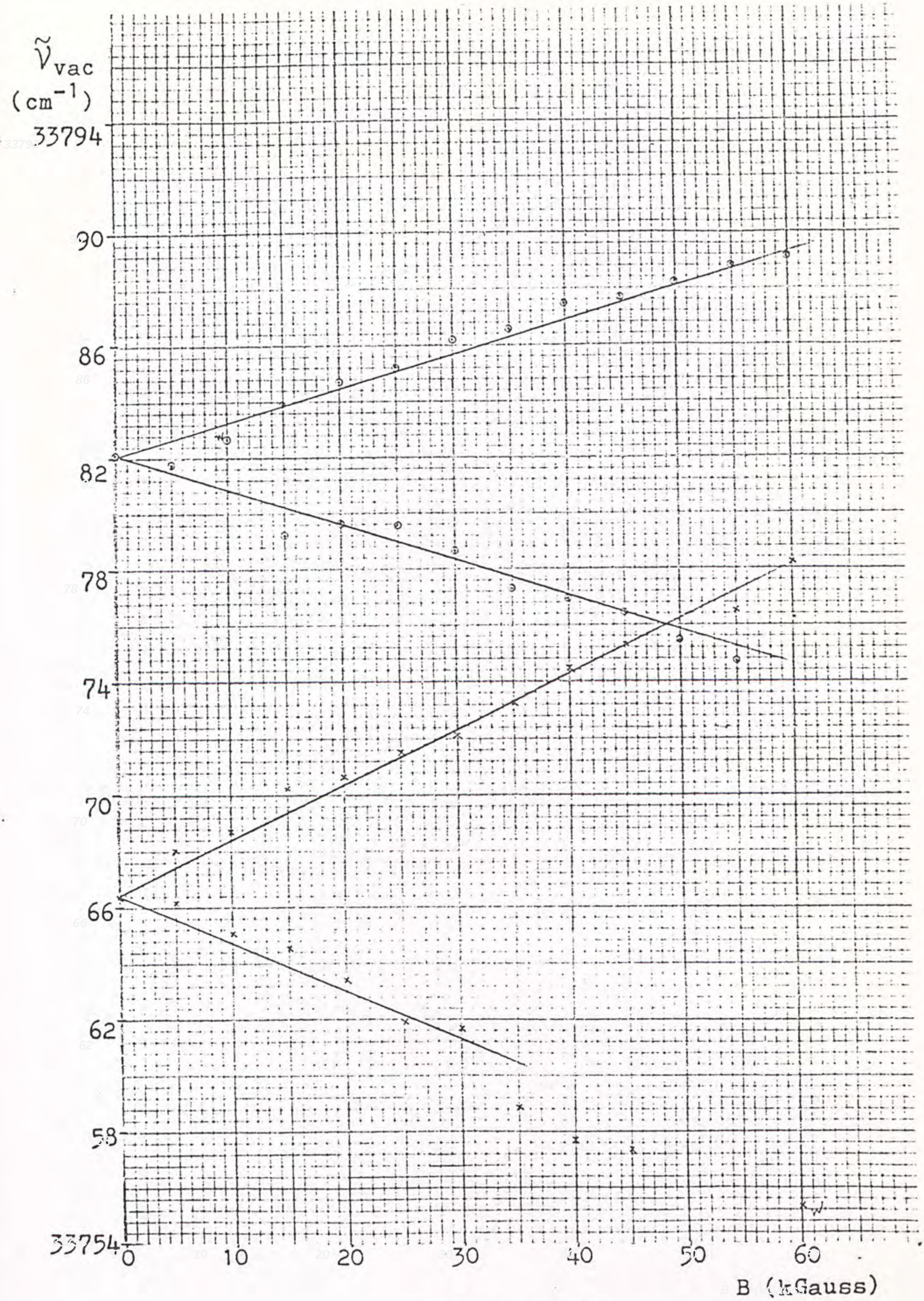

$\tilde{\nu}_{vac}$
(cm^{-1})
33794
90
86
82
78
74
70
66
62
58
33754
0
10
20
30
40
50
60
B (kGauss)

Figure 5-2(v)

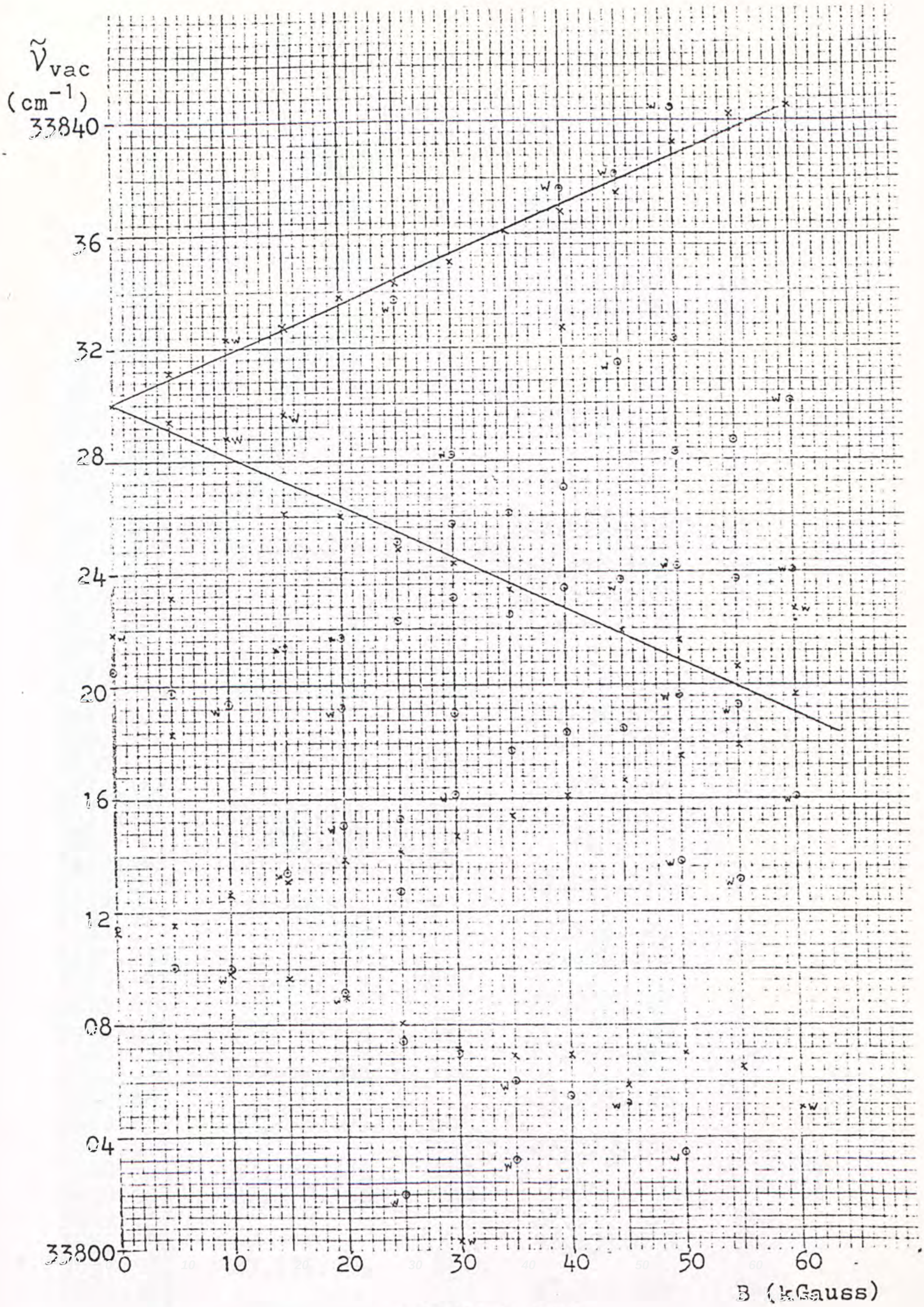

$\tilde{\nu}_{vac}$
(cm^{-1})
33840
36
32
28
24
20
16
12
08
04
33800
0
10
20
30
40
50
60
B (kGauss)

Figure 5-2(w)

Table 5-4

B(I) = 1kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
4011.299	24,922.535	0b		
4010.700			24,926.257	00
4010.483			24,927.606	00
4010.367	24,928.327	1bb		
4008.822	24,937.934	1b		
4007.973	24,943.216	0b		
3904.484			25,604.325	3
3904.129			25,606.654	5
3904.120	25,606.713	0bd		
3903.004			25,614.034	5bb
3901.946	25,620.979	1b		
3901.605			25,623.218	1b
3901.200	25,625.878	1b		
3900.211			25,632.376	5b
3899.750			25,635.406	5b
3898.947			25,640.686	5b
3898.874	25,641.166	0b		
3897.417	25,650.751	0b		
3893.144	25,678.904	0bbd		
3892.704			25,681.807	1b
3890.789			25,694.447	1b
3890.412	25,696.930	0bbd		
3832.168			26,087.488	3b
3831.934	26,089.081	3bd		
3830.547	26,098.527	3bd		
3829.843	26,103.324	5b		
3668.435			27,251.819	3
3668.292	27,252.881	5b		
3668.219			27,253.424	3
3667.253			27,260.602	8b
3667.197	27,261.019	8b		
3665.674			27,272.345	7
3665.632	27,272.657	7b		
3665.036			27,277.092	3bd
3664.914	27,278.000	1bd		
3662.883			27,293.125	5
3662.833	27,293.497	5b		
3660.518			27,310.758	1bd
3660.354	27,311.982	1bd		
3659.659	27,317.168	3bd		
3659.657			27,317.183	2bd
3657.752			27,331.410	5b
3657.580	27,332.695	5bbd		
3656.397			27,341.538	5b
3656.318	27,342.129	5b		
3574.137			27,970.796	3b
3574.124	27,970.898	3		
3531.075			28,311.894	7
3530.825	28,313.899	8b		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3530.708			28,314.837	8
3529.830			28,321.880	5s
3529.755	28,322.482	5		
3529.323			28,325.948	10bb
3529.260	28,326.454	10bb		
3528.202			28,334.948	3b
3528.149	28,335.374	3bd		
3527.335			28,341.912	3b
3527.239	28,342.684	3bd		
3525.475			28,356.865	10bbbd
3525.446	28,357.098	10bbb		
3524.449			28,365.119	10bb
3524.406	28,365.466	10bb		
3523.815			28,370.223	8
3523.790	28,370.424	6b		
3522.643			28,379.661	3b
3522.534	28,380.540	3		
3393.688	29,458.012	1b		
3392.835			29,465.418	3
3392.518			29,468.172	3s
3392.332	29,469.787	1b		
3390.862	29,482.562	0d		
3390.580	29,485.015	0d		
3389.739	29,492.330	4s		
3389.455	29.494.801	4s		
3268.385	30,587.333	7s		
3268.236			30,588.727	8b
3268.192	30,589.139	7s		
3267.371	30,596.825	8s		
3267.140	30,598.988	8s		
3266.256	30,607.269	7s		
3266.040	30,609.294	7s		
3265.499	30,614.365	5		
3264.481			30,623.911	7bb
3225.424	30,994.726	3		
3225.119	30,997.657	4s		
3224.825	31,000.483	2d		
3223.374			31,014.438	2
3223.212	31,015.996	0bd		
3223.129			31,016.795	2s
3222.493	31,022.916	4b		
3222.423			31,023.590	2
3221.890			31,028.722	2
3220.084	31,046.124	00		
3218.150	31,064.781	00		
3216.115	31,084.437	2bbd		
3178.423	31,453.045	0		
3177.445			31,462.725	1bb
3176.065			31,476.396	1bb
3031.014			32,982.657	2bd
3030.644	32,986.684	6b		
3030.519			32,988.044	5s
3030.259			32,990.875	5s
3030.094	32,992.671	00		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3029.726			32,996.678	4d
3029.533			32,998.780	4
3029.464	32,999.532	7		
3029.395			33,000.283	4
3029.352	33,000.752	7		
3028.679			33,008.085	5s
3028.455			33,010.526	5s
3028.303	33,012.183	4		
3028.067	33,014.756	4		
3005.776			33,259.585	7s
3005.526			33,262.351	7s
3005.522	33,262.395	3b		
3005.522	33,268.007	3b		
3004.422			33,274.573	5s
3004.260			33,276.367	5s
3003.926	33,280.067	00		
3002.928	33,291.127	6b		
3002.056	33,300.796	6		
3001.262			33,309.606	1bd
2999.861	33,325.162	4b		
2990.779	33,426.355	1s		
2990.235	33,432.436	1s		
2989.576			33,439.805	1b
2989.500	33,440.655	00		
2989.336			33,442.489	1s
2989.148			33,444.593	1s
2988.847	33,447.961	2s		
2988.635	33,450.333	3		
2960.681			33,766.149	6s
2960.514			33,768.054	6s
2959.311	33,781.780	6b		
2956.836	33,810.056	3bd		
2956.703			33,811.577	6b
2956.113			33,818.325	1
2955.988	33,819.755	4b		
2955.694			33,823.119	1
2955.139			33,829.471	5
2954.994			33,831.130	5

Table 5-5

B(I) = 2kA

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
4011.361	24,922.150	2b		
4010.636	24,926.655	2b		
4010.442			24,927.860	1bb
4009.924	24,931.080	2b		
4009.006	24,936.789	2d		
4008.899			24,937.455	1bb
4008.542	24,939.076	2d		
3904.774			25,602.424	8d
3903.905			25,608.123	7bd
3903.278			25,612.236	0
3902.511			25,617.270	7d
3902.319	25,618.530	2b		
3901.745			25,622.299	00
3901.732	25,622.384	7bd		
3901.130	25,626.338	3b		
3900.383			25,631.246	8d
3899.285			25,638.463	8d
3898.534			25,643.402	8bb
3894.532			25,669.753	00
3893.385	25,677.315	1b		
3892.463			25,683.397	2bb
3890.889	25,693.786	1b		
3890.453			25,696.666	00
3890.151	25,698.661	2bb		
3889.354	25,703.927	1b		
3832.164	26,087.515	4		
3832.050			26,088.291	5d
3831.780			26,090.129	5d
3831.666	26,090.905	4		
3830.832	26,096.586	0		
3830.339			26,099.944	3
3830.263	26,100.462	4d		
3829.593			26,105.028	6bd
3668.593			27,250.645	2bd
3668.404	27,252.049	5s		
3668.191	27,253.632	0		
3668.108			27,254.248	5
3667.661			27,257.570	00
3667.307			27,260.201	8
3667.208	27,260.937	9s		
3667.138			27,261.457	7s
3667.030	27,262.260	7		
3665.727			27,271.950	7b
3665.623	27,272.724	6b		
3665.277			27,275.299	3
3664.894			27,278.149	3
3664.797	27,278.871	1		
3662.915			27,292.886	6
3662.795	27,293.781	5		

(Cont.)

	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3660.583			27,310.273	1
3660.515	27,310.780	0		
3660.001			27,314.616	00
3659.919	27,315.228	1d		
3659.546			27,318.012	2
3659.461	27,318.646	1d		
3658.067	27,329.056	2d		
3657.708			27,331.739	5bd
3657.275	27,334.974	3bd		
3656.371			27,341.733	1bbd
3656.349	27,341.897	6bd		
3574.153			27,970.671	3
3574.116	27,970.960	3		
3531.311			28,310.002	5
3531.230	28,310.652	00		
3530.850	28,313.698	7		
3530.575			28,315.904	7
3530.484	28,316.634	0b		
3529.892			28,321.382	6s
3529.806	28,322.072	7s		
3529.617			28,323.589	10b
3529.517	28,324.391	10		
3529.210			28,326.855	10b
3529.116	28,327.610	10		
3528.154			28,335.333	6
3528.095	28,335.807	5		
3527.355			28,341.752	3bbd
3527.262	28,342.499	3bbd		
3525.453			28,357.042	9bbb
3525.368	28,357.725	9bbb		
3524.515			28,364.588	9bb
3524.445	28,365.152	8bb		
3523.828			28,370.118	6b
3523.772	28,370.569	6		
3522.596	28,380.040	3b		
3522.591			28,380.080	3b
3393.786	29,457.162	2s		
3393.489	29,459.740	2s		
3392.959			29,464.342	3
3392.270			29,470.326	3b
3390.950	29,481.797	1s		
3390.573	29,485.075	1s		
3390.304	29,487.415	00		
3389.743	29,492.295	3		
3389.194	29,497.072	3		
3378.825			29,587.590	00
3268.423	30,586.977	6s		
3268.358			30,587.586	9s
3268.141			30,589.616	9s
3268.066	30,590.318	6s		
3267.822	30,592.602	4s		
3267.409	30,596.469	8s		
3266.988	30,600.412	8s		
3266.332	30,606.557	6s		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3265.909	30,610.521	6s		
3265.482	30,614.524	5s		
3264.931			30,619.690	5s
3264.576			30,623.020	8s
3264.313			30,625.487	8s
3225.551	30,993.506	2s		
3225.275	30,996.158	1s		
3225.006	30,998.743	2s		
3224.632	31,002.339	2s		
3223.459			31,013.620	3
3223.342	31,014.745	3s		
3223.010			31,017.940	4
3222.990	31,018.133	3		
3222.473	31,023.109	5b		
3222.427			31,023.552	4
3221.703			31,030.523	4s
3221.241	31,034.974	2		
3220.578	31,041.362	3		
3218.160	31,064.685	2bbd		
3216.097	31,084.611	2bbd		
3177.624			31,460.953	1
3177.250			31,464.656	1b
3176.229			31,474.770	0
3175.913			31,477.902	0
3031.121			32,981.493	4bd
3030.820	32,984.768	7s		
3030.696			32,986.118	4b
3030.572	32,987.467	9s		
3030.137			32,992.203	5
3030.113	32,992.464	3bd		
3029.822			32,995.633	5bd
3029.564	32,998.443	9s		
3029.303	33,001.286	9		
3029.289			33,001.438	4d
3028.716			33,007.681	7
3028.711	33,007.736	3		
3028.331	33,011.878	3d		
3028.291			33,012.314	7
3027.961	33,015.911	4		
3005.828			33,259.009	5b
3005.600	33,261.532	00		
3005.374			33,264.033	6
3005.239	33,265.527	0d		
3005.009			33,268.073	2
3004.915	33,269.114	0		
3004.469			33,274.052	4b
3004.090			33,278.250	4
3003.006	33,290.262	6s		
3002.768	33,292.901	6s		
3002.140	33,299.865	6s		
3001.960	33,301.861	5s		
3001.394			33,308.141	00
2999.863	33,325.139	3bb		

	$\underline{\sigma}$		$\underline{\pi}$	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
2990.302	33,431.686	0b		
2989.684			33,438.597	2
2989.376			33,442.042	2b
2989.010			33,446.137	2
2988.882	33,447.569	0		
2988.505	33,451.788	1s		
2960.777			33,765.054	2s
2960.450			33,768.784	2s
2959.235	33,782.648	0bb		
2956.844			33,809.964	1d
2956.840	33,810.010	00		
2956.611			33,812.629	1d
2956.021	33,819.377	00		
2955.192			33,828.864	00
2954.885			33,832.378	00

Table 5-6

B(I) = 3kA

λ_{air}(Å)	$\underline{\sigma}$ $\tilde{\nu}_{vac}(cm^{-1})$	I	$\underline{\pi}$ $\tilde{\nu}_{vac}(cm^{-1})$	I
4012.796	24,913.237	1b		
4012.258	24,916.578	1b		
4012.093			24,917.603	0d
4011.268	24,922.727	3s		
4010.841	24,925.381	3s		
4010.528			24,927.326	1b
4010.345	24,928.463	3s		
4009.862	24,931.466	6s		
4009.595	24,933.126	1s		
3904.753			25,602.562	3
3904.013	25,607.414	0		
3903.649			25,609.802	7b
3902.301			25,618.649	7b
3902.170	25,619.509	1b		
3901.584	25,623.356	5b		
3901.545			25,623.613	1
3900.932	25,627.639	1b		
3900.739			25,628.907	1b
3900.289			25,631.864	5b
3899.215	25,638.924	0b		
3899.150			25,639.351	7bb
3898.632			25,642.758	5b
3898.468	25,643.836	0		
3897.039	25,653.239	0b		
3896.078	25,659.567	00		
3893.623	25,675.745	0bb		
3892.582			25,682.612	1bb
3890.251	25,698.000	3b		
3888.867			25,707.146	3b
3832.132	26,087.733	1b		
3832.041			26,088.352	5
3831.649			26,091.021	5
3831.530	26,091.832	3b		
3831.074	26,094.937	0b		
3829.972	26,102.445	5b		
3829.450			26,106.003	6b
3393.821	29,456.858	2s		
3393.472	29,459.887	2s		
3392.270			29,470.326	3b
3392.126			29,471.577	3b
3391.091	29,480.572	3		
3390.443	29,486.206	3		
3390.182	29,488.476	3		
3389.072	29,498.134	4s		
3379.766			29,579.353	00
3378.703			29,588.659	00
3268.570	30,585.602	7s		
3268.406			30,587.136	9s

(Cont.)

λ_{air}(A)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3268.105			30,589.953	9s
3267.988	30,591.049	7s		
3267.702	30,593.726	7s		
3267.375	30,596.788	6s		
3266.898	30,601.255	9s		
3266.456	30,605.396	9s		
3265.815	30,611.402	8s		
3265.510	30,614.261	6s		
3264.795			30,620.966	7s
3264.469			30,624.024	6s
3264.262			30,625.966	8s
3264.071			30,627.758	00
3226.423	30,985.130	0		
3225.841	30,990.720	1		
3225.363	30,995.312	3		
3224.832	31,000.416	5s		
3224.502	31,003.588	4		
3223.594			31,012.321	3
3223.502	31,013.206	2		
3222.899			31,019.008	4bb
3222.874	31,019.249	2		
3222.484			31,023.003	2d
3222.392	31,023.889	5b		
3221.574			31,031.766	4s
3221.315	31,034.261	00		
3220.430	31,042.789	2		
3218.048	31,065.766	2bbd		
3216.156	31,084.041	4bb		
3177.830			31,458.914	1b
3177.209			31,465.062	1b
3176.467			31,472.412	0
3175.747			31,479.547	1
3031.221			32,980.405	4d
3030.851	32,984.431	7s		
3030.782			32,985.182	4d
3030.544	32,987.772	7s		
3030.113			32,992.464	5bd
3029.846			32,995.371	4s
3029.610	32,997.942	9		
3029.208	33,002.321	9		
3029.163			33,002.811	4d
3028.695			33,007.910	5
3028.661	33,008.281	4		
3028.167			33,013.665	5
3028.118	33,014.200	3d		
3027.837	33,017.263	4		
3006.895			33,247.208	00
3005.982			33,257.305	5bd
3005.627	33,261.233	3b		
3005.366			33,264.122	3
3005.179	33,266.191	3b		
3005.124			33,266.800	5b
3004.814	33,270.232	3b		
3004.619			33,272.391	3

(Cont.)

λ_{air}(A)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3003.997			33,279.280	5b
3003.123	33,288.965	7		
3002.978	33,290.573	0		
3002.709	33,293.555	8s		
3002.202	33,299.177	7		
3001.888	33,302.660	7		
3001.322			33,308.940	2d
3000.852			33,314.157	2d
2999.828	33,325.528	1bbd		
2990.282	33,431.910	00		
2989.702			33,438.396	2d
2989.354			33,442.288	2
2989.140	33,444.682	00		
2988.937			33,446.954	2b
2988.393	33,453.042	1b		
2960.828			33,764.473	5
2960.324			33,770.221	5
2959.535	33,779.224	2d		
2956.870			33,809.667	4
2956.576			33,813.029	4
2956.542	33,813.418	00		
2955.847	33,821.368	00		
2955.433			33,826.105	3
2955.124			33,829.642	00
2954.847			33,832.813	3
2959.121	33,783.949	2d		

Table 5-7

B(I) = 3.2kA

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3668.804			27,249.078	3
3668.519	27,251.195	5		
3668.511			27,251.255	3
3668.241	27,253.260	0		
3667.990			27,255.125	7
3667.928	27,255.586	0		
3667.662	27,257.563	0d		
3667.242			27,260.684	9
3667.175	27,261.182	8		
3666.944	27,262.900	7		
3666.940			27,262.929	8
3665.711			27,272.069	7b
3665.654	27,272.494	7b		
3665.348			27,274.770	5
3665.306	27,275.083	00		
3664.830	27,278.625	2b		
3664.802			27,278.834	5
3663.595	27,287.821	3b		
3662.708			27,294.429	6
3662.698	27,294.503	6		
3660.507			27,310.840	2bd
3660.053	27,314.228	1d		
3659.470			27,318.579	2b
3659.413	27,319.005	3b		
3658.268	27,327.555	5b		
3658.187			27,328.160	2b
3657.782			27,331.186	4bd
3657.756	27,331.380	1		
3657.159	27,335.841	3b		
3656.416	27,341.396	6b		
3656.393			27,341.568	5b
3656.003			27,344.485	3bbd
3655.988	27,344.597	3bbd		
3574.321			27,967.791	00
3574.221	27,970.139	1s		
3573.992			27,971.931	00
3573.892	27,972.713	1s		
3531.518			28,308.343	3
3531.469	28,308.736	1d		
3530.931			28,313.049	2d
3530.918	28,313.153	7		
3530.495			28,316.545	8b
3530.420	28,317.147	2d		
3529.847			28,321.744	8bb
3529.721	28,322.754	10bb		
3529.125			28,327.538	8b
3529.082	28,327.883	10b		
3528.060			28,336.088	8b
3527.997	28,336.594	9		

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3527.663			28,339.277	1
3527.581	28,339.936	3d		
3527.287			28,342.298	00
3527.216	28,342.869	00		
3527.053			28,344.178	7
3526.996	28,344.636	5b		
3525.366			28,357.742	8bbb
3525.296	28,358.305	9bbb		
3524.509			28,364.637	8bb
3524.465	28,364.991	9bb		
3523.781			28,370.496	6
3523.765	28,370.625	7		
3522.477			28,380.999	3b
3522.466	28,381.087	3b		

Table 5-8

B(I) = 4kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
4012.776	24,913.362	1bb		
4012.331			24,916.125	0bd
4011.334	24,922.317	3s		
4011.143	24,923.504	3s		
4010.856			24,925.287	1b
4010.042	24,930.347	6s		
4009.337	24,934.730	1		
3905.104			25,600.260	1b
3904.034	25,607.277	0b		
3903.691			25,609.527	5b
3903.336	25,611.856	0		
3902.818	25,615.255	1b		
3902.239			25,619.056	7b
3902.073	25,620.145	1b		
3901.506	25,623.869	5b		
3900.985			25,627.291	3b
3900.865	25,628.079	1b		
3900.183			25,632.560	3b
3899.551	25,636.846	0		
3899.127			25,639.502	6b
3898.644			25,642.679	5b
3898.413	25,644.198	0		
3896.966	25,653.720	0b		
3893.525	25,676.392	00		
3892.658			25,682.110	00
3892.333	25,684.255	0b		
3891.441	25,690.142	1b		
3890.678			25,695.180	00
3890.410	25,696.950	1b		
3887.666	25,715.087	00		
3832.352	26,086.235	1bbd		
3832.253			26,086.909	5b
3831.765			26,090.231	5
3831.367	26,092.942	1bbd		
3830.153			26,101.212	00
3829.991			26,102.316	3
3829.989	26,102.329	3b		
3829.550			26,105.322	5b
3668.956			27,247.949	1
3668.869	27,248.595	3b		
3668.599			27,250.601	00
3668.589	27,250.675	5		
3668.261	27,253.112	3		
3667.912	27,255.705	3		
3667.903			27,255.772	7s
3667.562	27,258.306	2		
3667.191			27,261.063	8
3667.081	27,261.881	8		
3666.805	27,263.933	7s		

(Cont.)

	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3666.792			27,264.030	6
3665.744			27,271.824	6b
3665.714	27,272.047	6b		
3665.438			27,274.101	5
3665.432	27,274.145	00		
3664.974	27,277.554	00		
3664.745	27,279.258	00		
3664.740			27,279.295	5
3663.824			27,286.115	00
3663.493			27,288.580	00
3663.453	27,288.878	4b		
3662.599			27,295.241	6b
3662.573	27,295.435	6b		
3660.537			27,310.616	3bbd
3660.315	27,312.273	3bbd		
3659.413			27,319.005	5
3659.383	27,319.229	5b		
3658.326	27,327.122	3bbd		
3657.788			27,331.141	5d
3656.987			27,337.127	1d
3656.968	27,337.269	5b		
3656.279			27,342.421	7b
3656.286	27,342.368	7b		
3655.741			27,346.444	5bd
3655.665	27,347.013	5b		
3574.381			27,968.887	3s
3574.221	27,970.139	3s		
3573.956			27,972.212	3s
3573.820	27,973.277	3s		
3531.744			28,306.532	3
3531.703	28,306.860	1		
3531.279	28,310.259	00		
3530.982			28,312.640	1
3530.970	28,312.736	7b		
3530.624			28,315.511	00
3530.577	28,315.888	00		
3530.369			28,317.556	8
3530.292	28,318.174	00		
3529.831			28,321.872	8bbd
3529.783	28,322.257	7bb		
3529.201	28,326.928	5d		
3529.053			28,328.115	8
3529.018	28,328.396	8b		
3527.920			28,337.213	8bb
3527.817	28,338.040	8bbd		
3527.237			28,342.700	5
3527.200	28,342.997	3b		
3526.957			28,344.950	8s
3526.923	28,345.223	8		
3525.246			28,358.707	8bbb
3525.184	28,359.206	7bbd		
3524.550			28,364.307	7bbd
3524.461	28,365.023	7b		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3524.218	-		28,366.979	5
3524.202	28,367.107	5		
3523.756			28,370.698	7d
3523.728	28,370.923	7		
3522.942			28,377.253	5d
3522.384	28,381.748	4		
3393.930	29,455.912	2s		
3393.434	29,460.217	2s		
3393.279			29,461.563	3b
3391.876			29,473.749	4b
3391.198	29,479.641	4		
3390.240	29,487.971	4bb		
3388.954	29,499.161	5		
3268.638	30,584.965	7s		
3268.421			30,586.996	8s
3268.011			30,590.833	8s
3267.845	30,592.387	7s		
3267.708	30,593.670	8s		
3267.161	30,598.792	5		
3266.763	30,602.519	9s		
3266.545	30,604.562	7s		
3265.728	30,612.218	8s		
3265.476	30,614.580	7s		
3264.769			30,621.210	8s
3264.166			30,626.866	8
3263.980			30,628.611	00
3226.246	30,986.829	1		
3225.926	30,989.903	3		
3225.495	30,994.044	3		
3224.672	31,001.954	5		
3224.349	31,005.059	3		
3223.504	31,013.187	00		
3223.237	31,015.756	1		
3222.862			31,019.364	5s
3222.557	31,022.300	2		
3222.351	31,024.283	4bb		
3221.401			31,033.452	3s
3220.233	31,044.784	2		
3219.620	31,050.598	00		
3218.079	31,065.467	4bb		
3217.153	31,074.408	0b		
3216.067	31,084.901	5b		
3177.854			31,458.676	2
3177.144			31,465.706	2
3176.438			31,472.699	0
3175.608			31,480.925	1
3031.384			32,978.632	4b
3030.999			32,982.820	00
3030.857	32,984.366	5s		
3030.456	32,988.730	5s		
3030.229	32,991.201	3		
3030.206			32,991.452	6
3029.808	32,995.785	00		
3029.793			32,995.949	7s

	σ		π	(cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3029.594	32,998.116	6		
3029.094	33,003.562	7b		
3029.049			33,004.053	6
3028.678	33,008.095	3d		
3028.608			33,008.858	5d
3028.020	33,015.268	1		
3028.020			33,015.268	6
3027.689	33,018.877	5b		
3006.997			33,246.080	2d
3006.298			33,253.810	5b
3005.622	33,261.289	1		
3005.341	33,264.398	0		
3005.243			33,265.483	6b
3005.025	33,267.896	1b		
3004.804			33,270.343	3
3004.656	33,271.982	2		
3004.334			33,275.548	2
3004.069			33,278.483	3d
3003.144	33,288.732	6b		
3002.842	33,292.080	2		
3002.633	33,294.397	6		
3002.233	33,298.833	5		
3001.837	33,303.226	5		
3001.314			33,309.029	1bd
3000.926			33,313.335	1bd
2999.955	33,324.117	00		
2999.584	33,328.239	00		
2991.251	33,421.080	1b		
2990.134	33,433.565	0		
2989.751			33,437.848	3b
2989.299			33,442.903	3
2989.201	33,444.000	1b		
2988.808			33,448.397	4
2988.255	33,454.587	1b		
2960.924			33,763.378	8
2960.289			33,770.620	8
2959.501	33,779.612	5b		
2959.053	33,784.726	5bd		
2956.922			33,809.073	6
2956.911	33,809.198	00		
2956.497			33,813.932	5
2956.401	33,815.030	00		
2956.029	33,819.286	00		
2955.821	33,821.665	00		
2955.433			33,826.105	5b
2954.755			33,833.867	5bd

Table 5-9

$B(I) = 5\,kA$	σ		π	
λ_{air} (Å)	$\tilde{\nu}_{vac}$ (cm^{-1})	I	$\tilde{\nu}_{vac}$ (cm^{-1})	I
4011.002	24,924.380	3b		
4010.688	24,926.331	1		
4009.566	24,933.306	00		
4009.293	24,935.004	5b		
4008.909			24,937.392	1b
4008.182	24,941.916	1s		
4007.916	24,943.571	6s		
4007.150	24,948.339	1		
3905.281			25,599.100	1
3903.928			25,607.972	5
3903.836	25,608.575	3b		
3903.446			25,611.134	7s
3902.999	25,614.067	3b		
3902.112	25,619.889	3b		
3902.084			25,620.073	7b
3901.451	25,624.230	6s		
3901.162			25,626.128	5b
3900.589	25,629.892	1b		
3899.950			25,634.092	1
3899.561	25,636.649	0		
3899.227			25,638.845	3s
3898.717			25,642.199	5
3898.507			25,643.580	5
3898.286	25,645.034	0		
3896.910	25,654.089	0		
3892.829			25,680.982	0b
3892.190	25,685.198	0		
3891.536	25,689.515	1		
3890.519			25,696.230	00
3890.374	25,697.188	5		
3887.580	25,715.656	00		
3832.328	26,086.399	00		
3832.283			26,086.705	3b
3831.617			26,091.239	3b
3831.403	26,092.696	1bbd		
3830.517			26,098.731	1b
3829.965			26,102.493	3
3829.799	26,103.624	3b		
3829.521			26,105.529	5b
3668.969			27,247.853	2b
3668.959	27,247.927	4b		
3668.596	27,250.623	4		
3667.858			27,256.106	7s
3667.850	27,256.165	3d		
3667.144			27,261.413	8
3667.030	27,262.260	8		
3666.699	27,264.721	6s		
3666.588			27,265.546	6s
3665.835			27,271.147	6bb

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3665.818	27,271.273	6b		
3665.522			27,273.476	7s
3665.472	27,273.848	3		
3665.036			27,277.092	0
3665.024	27,277.181	0		
3664.742	27,279.280	0		
3664.740			27,279.295	4
3663.815			27,286.182	0
3663.795	27,286.331	00		
3663.416	27,289.154	4		
3663.262			27,290.301	0
3663.214	27,290.659	4		
3662.510			27,295.904	6
3662.467	27,296.225	6		
3662.382			27,296.858	6
3662.327	27,297.268	6		
3661.513	27,303.337	00		
3660.674			27,309.594	3b
3660.315	27,312.273	1b		
3659.416			27,318.982	3d
3659.367	27,319.348	6		
3658.481	27,325.964	4b		
3658.019	27,329.415	4bbd		
3657.917			27,330.177	6bbbd
3656.904			27,337.748	00
3656.815	27,338.413	6b		
3656.201	27,343.004	7bd		
3656.140			27,343.460	8bd
3655.489			27,348.329	2bb
3655.395	27,349.033	2bbd		
3574.501			27,967.948	2
3574.425	27,968.542	3s		
3573.932			27,972.400	3
3573.872	27,972.870	3s		
3532.269			28,302.324	00
3531.923	28,305.097	00		
3531.892			28,305.345	4
3531.425	28,309.088	2bb		
3531.418			28,309.145	3
3531.089			28,311.782	5
3531.082	28,311.838	8b		
3530.278			28,318.286	10bb
3530.222	28,318.735	9b		
3529.844			28,321.768	9b
3529.749	28,322.530	9bb		
3529.260			28,326.454	0
3529.021	28,328.372	9b		
3528.995			28,328.581	10
3528.161			28,335.277	6bd
3528.072	28,335.992	5bd		
3527.804			28,338.145	9
3527.717	28,338.843	9b		
3527.642			28,339.446	9
3527.176	28,343.190	0		

(Cont.)

	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3526.950	28,345.006	9		
3526.943			28,345.062	9
3525.077	28,360.066	10bbb		
3524.618	28,363.759	10bb		
3524.611			28,363.816	9b
3524.272	28,366.544	9b		
3523.760			28,370.666	8
3523.751	28,370.738	8		
3523.589			28,372.042	4d
3523.530	28,372.517	1d		
3522.275	28,382.626	4bb		
3522.259			28,382.755	3bb
3394.022	29,455.114	0		
3393.371			29,460.764	1bb
3393.369	29,460.782	0		
3391.793			29,474.470	4b
3391.245	29,479.233	3		
3390.250	29,487.884	4b		
3389.949	29,490.503	1		
3388.755	29,500.893	5		
3268.701	30,584.376	6s		
3268.501			30,586.247	9s
3267.990			30,591.030	9s
3267.792	30,592.883	8b		
3266.637	30,603.700	9bb		
3265.575	30,613.652	8s		
3265.457	30,614.758	5d		
3265.038	30,618.687	00		
3264.868			30,620.281	9s
3264.590	30,622.889	00		
3264.124	30,627.260	9		
3263.865	30,629.691	2d		
3226.103	30,988.203	5		
3225.692	30,992.151	3b		
3224.587	31,002.771	5s		
3224.277	31,005.752	3d		
3223.585	31,012.908	0		
3223.300	31,015.150	1bd		
3222.972			31,018.306	3ss
3222.780			31,020.154	3ss
3222.362	31,024.177	3bbd		
3221.242			31,034.964	3s
3220.058	31,046.375	1b		
3218.139	31,064.887	4bb		
3217.011	31,075.779	2b		
3216.074	31,084.833	5b		
3178.004			31,457.191	1b
3177.097			31,466.172	2b
3175.541			31,481.589	1
3031.441			32,978.012	00
3030.934	32,983.528	5		
3030.432	32,988.991	5		
3030.324			32,990.167	3b
3030.243	32,991.049	3d		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3029.692	32,997.049	5b		
3029.661			32,997.386	5
3029.159			33,002.854	2
3029.010	33,004.478	6		
3028.856			33,006.156	3d
3028.726	33,007.572	3bd		
3028.293			33,012.292	3d
3027.866			33,016.947	5
3027.841	33,017.220	2		
3027.573	33,020.142	3		
3006.872			33,247.462	2bd
3006.254			33,254.296	4d
3005.661	33,260.857	4		
3005.440	33,263.303	00		
3004.952			33,268.704	6
3004.908	33,269.191	1		
3004.713			33,271.351	2d
3004.611	33,272.480	2		
3004.008			33,279.159	1
3003.232	33,287.757	7b		
3002.731	33,293.311	8s		
3002.469	33,296.216	8s		
3002.261	33,298.523	8s		
3001.777	33,303.891	7b		
3001.701			33,304.735	0
3000.716	33,315.667	00		
3000.708			33,315.755	4
2999.980	33,323.840	2bd		
2999.610	33,327.950	2bd		
2991.243	33,421.170	00		
2989.885	33,436.349	1bd		
2989.802			33,437.277	5b
2989.281			33,443.105	4
2989.234	33,443.631	1bd		
2988.747			33,449.080	5
2988.153			33,455.729	3
2961.047			33,761.976	4
2960.211			33,771.510	4d
2959.505	33,779.566	4b		
2959.011	33,785.205	5b		
2957.540	33,802.008	00		
2957.068	33,807.403	3		
2957.013			33,808.032	5
2956.603	33,812.720	0		
2956.480			33,814.127	5
2956.382	33,815.248	1		
2955.764	33,822.318	2		
2955.541			33,824.869	5b
2955.517	33,825.144	2		
2954.767	33,833.729	0		
2954.720			33,834.268	5b
2952.968	33,854.341	0		

Table 5-10

B(I) = 6kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
4011.458	24,921.547	3b		
4011.107	24,923.728	3bd		
4009.708	24,932.423	3bd		
4009.256	24,935.234	3b		
4008.837			24,937.840	2b
4008.477	24,940.080	4		
4008.242			24,941.542	00
4008.035	24,942.830	6bd		
4007.208	24,947.978	00		
3905.438			25,598.071	0
3904.198			25,606.201	4b
3903.758	25,609.087	2b		
3903.248			25,612.433	5bd
3902.954	25,614.362	1bb		
3902.437			25,617.756	0
3902.170	25,619.509	2bd		
3901.895			25,621.314	6b
3901.321			25,625.084	5b
3901.305	25,625.189	6		
3900.425	25,630.970	3bd		
3899.722	25,635.590	0		
3899.635			25,636.162	3b
3899.233			25,638.805	3bd
3898.478			25,643.771	6bb
3898.169	25,645.803	1b		
3897.291	25,651.581	00		
3896.652	25,655.787	2bbd		
3892.669			25,682.038	0b
3892.111	25,685.720	0		
3891.660	25,688.696	00		
3890.298	25,697.690	4bb		
3889.846	25,700.676	0		
3832.373			26,086.092	5
3831.572			26,091.546	4
3831.518	26,091.913	5bd		
3831.205	26,094.045	0		
3830.532			26,098.629	2
3829.989			26,102.329	5
3829.707	26,104.251	5		
3829.461			26,105.928	4
3828.597	26,111.819	00		
3669.088			27,246.969	2
3669.043	27,247.303	5s		
3668.908			27,248.306	2
3668.886	27,248.469	0		
3668.630			27,250.371	00
3668.554	27,250.935	3		
3667.807			27,256.485	7

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3667.745	27,256.946	4		
3667.096			27,261.770	8
3667.036	27,262.216	6		
3666.848			27,263.613	2
3666.840	27,263.673	8		
3666.557			27,265.777	2
3666.515	27,266.089	7s		
3666.377			27,267.116	7s
3666.271	27,267.904	0		
3666.011			27,269.838	0d
3665.939	27,270.373	5		
3665.826			27,271.214	6
3665.806	27,271.363	5		
3665.520			27,273.490	7
3665.491	27,273.706	5		
3664.694			27,279.638	6
3664.618	27,280.203	4		
3664.093			27,284.112	0
3663.093			27,286.026	1
3663.806	27,286.249	2		
3663.314			27,289.914	0
3663.240	27,290.465	7s		
3663.057			27,291.828	1
3663.040	27,291.955	7s		
3662.355			27,297.060	7s
3662.340	27,297.171	7s		
3662.123			27,298.789	7s
3662.116	27,298.841	7s		
3660.777			27,308.826	3d
3660.750	27,309.027	00		
3660.361	27,311.929	0b		
3659.385			27,319.214	3b
3659.355	27,319.438	5b		
3658.612	27,324.985	3b		
3658.233			27,327.816	5bd
3657.887	27,330.401	3bb		
3657.734			27,331.544	7b
3656.758	27,338.839	4b		
3656.741			27,338.966	00
3656.138	27,343.475	7bd		
3655.979			27,344.664	8b
3655.275			27,349.931	4b
3655.153	27,350.843	3bb		
3574.617			27,967.040	3
3574.445	27,968.386	3s		
3573.828			27,973.214	3s
3573.804	27,973.402	3s		
3532.528			28,200.249	00
3532.028			28,304.256	2
3531.528	28,308.263	1bb		
3531.423			28,309.104	2s
3531.167			28,311.189	2s
3531.161	28,311.205	9s		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3530.295			28,318.150	9bb
3530.219	28,318.759	9b		
3529.864			28,321.607	9b
3529.694	28,322.971	9bb		
3528.945	28,328.982	10		
3528.929			28,329.111	8ss
3528.784			28,330.275	8ss
3528.759	28,330.476	4d		
3528.209			28,334.892	6bd
3528.095	28,335.807	6bb		
3527.747			28,338.602	9
3527.537	28,340.289	8bb		
3527.449			28,340.996	9
3527.173			28,343.214	2
3527.142	28,343.463	5		
3526.886			28,345.520	10
3526.868	28,345.665	8		
3524.850			28,361.893	9bbbb
3524.791	28,362.367	10bbbb		
3524.277			28,366.504	7b
3524.272	28,366.544	9b		
3523.705			28,371.108	7
3523.667	28,371.414	8		
3523.480			28,372.920	6
3523.435	28,373.282	4d		
3522.977			28,376.971	00
3522.202			28,383.215	3
3522.166	28,383.505	6		
3522.018			28,384.697	4
3522.013	28,384.738	2d		
3521.455			28,389.235	0
3394.062	29,454.767	00		
3393.594			29,458.828	00
3393.284			29,461.520	00
3393.243	29,461.876	00		
3391.382	29,478.042	3bb		
3390.439	29,486.241	3b		
3390.109	29,489.111	3s		
3389.818	29,491.642	3s		
3389.485			29,494.540	5bd
3388.580	29,502.417	5s		
3268.804	30,583.412	5s		
3268.558			30,585.714	9s
3267.960			30,591.311	10
3267.931	30,591.582	8s		
3267.653	30,594.185	7s		
3267.180	30,598.614	00		
3266.583	30,604.206	9bb		
3266.118	30,608.563	0		
3265.474	30,614.599	8b		
3264.956			30,619.456	9s
3264.069			30,627.776	10b
3226.222	30,987.060	2s		

	σ		π		(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I	
3225.856	30,990.576	1d			
3224.423			31,004.348	0	
3224.370	31,004.858	5s			
3224.127			31,007.194	1	
3224.073	31,007.714	3s			
3223.331	31,014.851	3			
3223.121			31,016.872	2	
3222.748			31,020.462	2s	
3222.022	31,027.451	2bbd			
3221.315			31,034.261	3s	
3219.763	31,049.219	1d			
3218.184	31,064.453	1d			
3216.101	31,084.572	4bd			
3178.059			31,456.647	0	
3176.984			31,467.291	2	
3175.506			31,481.936	1	
3031.701			32,975.183	2	
3031.400			32,978.458	2	
3030.953	32,983.321	6			
3030.522			32,988.012	3bb	
3030.399	32,989.351	6			
3030.088	32,992.736	0			
3029.667	32,997.321	6b			
3029.562			32,998.464	7	
3029.214	32,998.809	1b			
3029.185			33,002.571	2	
3028.868	33,006.025	6b			
3028.709			33,007.758	3b	
3028.535	33,009.654	1			
3028.063			33,014.799	3	
3027.705			33,018.703	4s	
3027.648	33,019.324	0			
3027.432	33,021.680	5b			
3006.367			33,253.047	3	
3005.694	33,260.492	3b			
3005.333	33,264.487	3b			
3004.826			33,270.099	6b	
3004.761	33,270.819	4			
3004.582	33,272.801	4			
3003.807			33,281.385	6	
3003.294	33,287.070	6b			
3002.614	33,294.608	6s			
3002.321	33,297.857	6			
3001.790			33,303.747	1	
3001.730	33,304.913	5b			
3000.528			33,317.754	3	
2999.479	33,329.406	0			
2990.309	33,431.608	00			
2989.875			33,436.461	5b	
2989.838	33,436.875	1b			
2989.411	33,441.650	0			
2989.203			33,443.977	4	
2988.680			33,449.830	6	

	σ		π		(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I	
2987.974	33,457.735	3			
2961.065			33,761.770	5	
2960.158			33,772.115	6b	
2959.582	33,778.687	6			
2958.925	33,786.187	6			
2957.681			33,800.397	0	
2957.107	33,806.957	2			
2957.044			33,807.678	5	
2956.425			33,814.756	5	
2956.307	33,816.106	0			
2956.050	33,819.045	3			
2955.692	33,823.141	3			
2955.584			33,824.377	5	
2955.474	33,825.636	2			
2955.247	33,828.234	0			
2954.663			33,834.920	6b	

Table 5-11

B(I) = 7kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
4011.678	24,920.180	4		
4011.228	24,922.976	5bd		
4010.785			24,925.729	0
4010.043			24,930.341	0
4009.902	24,931.217	4b		
4009.648	24,932.796	00		
4009.077	24,936.348	4		
4008.907			24,937.405	2bd
4008.652	24,938.991	4		
4008.010	24,942.986	7		
4007.139	24,948.407	2d		
3904.376			25,605.034	3
3903.700	25,609.468	3bd		
3903.251	25,612.413	2b		
3903.068			25,613.614	5
3902.582	25,616.804	00		
3902.287	25,618.740	4bd		
3901.669			25,622.798	6bb
3901.192	25,625.931	7		
3900.232	25,632.238	4d		
3899.773	25,635.255	00		
3899.295			25,638.398	3bd
3898.501	25,643.619	00		
3898.300			25,644.941	6bb
3897.964	25,647.152	00		
3896.359	25,657.716	0b		
3894.054	25,672.904	0b		
3892.722			25,681.688	00
3892.531	25,682.948	0bb		
3891.842	25,687.495	0bb		
3890.442			25,696.739	00
3890.394	25,697.056	4bd		
3889.948	25,700.002	2bb		
3832.971	26,082.023	0bb		
3832.416			26,085.800	3
3831.641	26,091.076	2		
3831.474			26,092.213	3
3831.300	26,093.398	2		
3831.045	26,095.135	2		
3830.524			26,098.684	2
3830.007			26,102.207	2
3829.524	26,105.499	6		
3829.452			26,105.990	4
3828.644	26,111.499	1		
3669.180			27,246.286	3
3669.155	27,246.472	5		
3668.934			27,248.113	3
3668.924	27,248.187	00		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3668.565			27,250.853	00
3668.556	27,250.920	1		
3667.974			27,255.244	0d
3667.729			27,257.065	8s
3667.721	27,257.124	4d		
3666.997			27,262.505	9
3666.964	27,262.751	4		
3666.740			27,264.416	5
3666.716	27,264.595	8		
3666.398			27,266.959	5
3666.395	27,266.982	6s		
3666.161			27,268.722	6
3666.111	27,269.094	5		
3665.896	27,270.693	5		
3665.876			27,270.842	6
3665.513	27,273.543	5		
3665.502			27,273.624	7b
3664.678	27,279.757	0		
3664.658			27,279.906	6
3664.131			27,283.829	2
3663.965	27,285.065	00		
3663.758			27,286.607	2
3663.579	27,287.940	00		
3663.177			27,290.934	4
3662.918	27,292.858	6		
3662.848			27,293.386	4
3662.608	27,295.174	6		
3662.257			27,297.790	7
3662.012	27,299.616	6		
3661.929			27,300.235	7s
3661.720	27,301.793	6		
3661.321			27,304.768	00
3660.862			27,308.192	00
3659.394			27,319.146	2d
3659.132	27,321.102	4b		
3658.390	27,326.644	2bb		
3658.333			27,327.069	5b
3657.664	27,332.067	2b		
3657.582			27,332.680	6b
3657.338	27,334.504	2b		
3656.623			27,339.848	0b
3656.414	27,341.411	4b		
3655.857	27,345.577	6b		
3655.820			27,345.853	6bb
3655.589	27,347.581	1d		
3655.075			27,351.427	3b
3654.724	27,354.054	1bb		
3574.742			27,966.062	2
3574.541	27,967.635	3s		
3573.856	27,972.995	3s		
3573.752			27,973.809	3s
3532.811			28,297.982	2
3532.196			28,302.909	4s

(Cont.)

	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3531.537			28,305.191	5s
3531.266			28,310.363	5
3531.248	28,310.507	8s		
3530.565			28,315.984	8s
3530.319	28,317.957	8bd		
3530.269			28,318.358	7b
3529.903			28,321.294	7b
3529.678	28,323.100	9bbd		
3528.973	28,328.758	7s		
3528.880			28,329.504	6s
3528.845	28,329.785	7s		
3528.643			28,331.407	5
3528.568	28,332.009	3		
3528.413			28,333.254	4
3528.295	28,334.201	5d		
3528.154			28,335.333	2bd
3528.081	28,335.920	3bd		
3527.662			28,339.285	9b
3527.355	28,341.752	9bbb		
3527.262			28,342.499	9b
3526.844	28,345.858	9b		
3526.841			28,345.882	9b
3524.741			28,362.770	10bbbb
3524.652	28,363.486	10bbb		
3524.265			28,366.600	9
3524.240	28,366.802	8b		
3523.662			28,371.455	7
3523.626	28,371.744	8b		
3523.444			28,373.210	6
3523.407	28,373.508	4d		
3522.077			28,384.222	4
3522.026	28,384.633	4s		
3521.824			28,386.261	5d
3521.795	28,386.495	3		
3393.090	29,463.204	00		
3393.164	29,462.561	0		
3391.498	29,477.034	3bd		
3391.433			29,477.599	5b
3390.608	29,484.771	3		
3389.985	29,490.189	4		
3389.692	29,492.738	3		
3388.430	29,503.723	5b		
3268.901	30,582.505	5s		
3268.629			30,585.050	9s
3268.049	30,590.478	8s		
3267.910			30,591.779	9
3267.563	30,595.027	6s		
3266.961	30,600.665	2bd		
3266.431	30,605.630	9		
3266.036	30,609.331	0		
3265.383	30,615.452	9		
3265.018			30,618.874	7s
3264.023			30,628.208	8b

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3263.757			30,630.704	2d
3226.386	30,985.485	2		
3225.930	30,989.865	1d		
3224.271			31,005.810	2
3224.264	31,005.877	6s		
3223.984	31,008.570	4s		
3223.910			31,009.281	2
3223.347	31,014.697	4		
3223.139			31,016.699	1bb
3222.668			31,021.232	3s
3222.013	31,027.538	3d		
3221.741	31,030.143	0		
3220.912			31,038.143	4
3219.657	31,050.241	1d		
3218.243	31,063.884	3bd		
3216.704	31,078.745	2d		
3216.085	31,084.727	5bd		
3178.165			31,455.598	1b
3176.880			31,468.321	2bd
3175.414			31,482.848	1bd
3031.980			32,972.149	1
3031.548			32,976.848	2
3031.030	32,982.483	5		
3030.755			32,985.476	3
3030.440			32,988.904	3
3030.418	32,989.144	5b		
3030.025	32,993.422	4		
3029.763	32,996.275	5		
3029.625	32,997.778	5		
3029.425			32,999.957	6
3028.893	33,005.753	3d		
3028.748	33,007.333	5		
3028.465			33,010.417	4b
3028.305	33,012.161	3		
3027.847			33,017.154	4
3027.508			33,020.851	5
3027.320	33,022.902	6		
3006.962			33,246.467	00
3006.441			33,252.228	2bd
3005.764	33,259.717	3		
3004.707			33,271.417	6b
3004.539	33,273.277	4b		
3003.722			33,282.327	5
3003.341	33,286.549	5s		
3002.555	33,295.262	6		
3002.340	33,297.647	3d		
3002.214	33,299.044	3d		
3001.861			33,302.960	0
3001.646	33,305.345	5		
3000.646			33,318.720	4
3000.087	33,322.651	00		
2999.457	33,329.650	0		
2989.922			33,435.935	5b

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$ (Cont.)	I
2989.726	33,438.127	0		
2989.502	33,440.633	0		
2989.144			33,444.637	4d
2988.558			33,451.195	5
2988.532	33,451.486	00		
2987.931			33,458.214	3
2961.320			33,758.863	1bbd
2960.052			33,773.324	6
2959.705	33,777.283	5b		
2958.898	33,786.495	5b		
2957.436	33,803.197	0		
2957.189	33,806.020	00		
2957.105			33,806.980	4
2956.362			33,815.476	4
2956.166	33,817.718	1bb		
2955.749	33,822.489	1		
2955.666			33,823.439	4
2955.429	33,826.151	1		
2954.595	33,855.699	00b		
2954.561			33,836.088	4b

Table 5-12

B(I) = 8kA	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
4011.857	24,919.065	3bd		
4011.240	24,922.901	4bb		
4010.797			24,925.654	1b
4010.168			24,929.564	1b
4010.104	24,929.961	4bd		
4009.591	24,933.151	2d		
4009.040			24,936.578	2bd
4009.035	24,936.609	4		
4008.769	24,938.263	4s		
4007.909	24,943.614	6d		
4007.084	24,948.750	2bb		
3904.608			25,603.512	4
3903.555	25,610.419	2bd		
3902.886			25,614.809	6
3902.389	25,618.071	3b		
3901.601			25,623.245	6bb
3901.098			25,626.548	00
3901.061	25,626.792	6		
3899.980	25,633.895	3b		
3899.436	25,637.471	0		
3899.270			25,638.562	0
3899.001			25,640.331	0
3898.319			25,644.817	4d
3897.963			25,647.159	4d
3897.788	25,648.310	0b		
3895.737	25,661.813	0bb		
3894.170	25,672.139	0bb		
3892.485			25,683.252	00
3891.777	25,687.924	0bd		
3890.399	25,697.023	0bd		
3890.023	25,699.506	3bd		
3888.542			25,709.294	00
3885.601	25,728.753	00		
3833.031	26,081.614	1bb		
3832.507			26,085.180	4
3831.830	26,089.789	2		
3831.436			26,092.472	4
3831.412	26,092.635	3		
3830.976	26,095.605	2		
3830.606			26,098.125	2
3830.065			26,101.811	3
3829.459			26,105.942	6
3829.379	26,106.487	6d		
3828.812	26,110.353	2b		
3394.242			29,453.205	0
3394.157	29,453.942	1		
3393.722			29,457.717	0
3393.121	29,462.935	1bd		
3391.626	29,475.921	3b		

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3391.314			29,478.633	6s
3390.826	29,482.875	3		
3389.863	29,491.251	4s		
3389.596	29,493.574	4		
3388.321	29,504.672	5s		
3268.978	30,581.784	6s		
3268.646			30,584.891	8s
3268.160	30,589.439	8s		
3267.847			30,592.368	8s
3267.077	30,599.578	4d		
3266.297	30,606.885	10b		
3265.861	30,610.971	00		
3265.255	30,616.652	9s		
3265.079			30,618.302	8s
3263.940			30,628.987	8b
3263.676			30,631.464	2
3226.533	30,984.073	3		
3226.182	30,987.444	3		
3224.110	31,007.358	6s		
3223.867	31,009.695	5		
3223.459			31,013.620	3
3223.417	31,014.024	5		
3222.632			31,021.578	3b
3221.941	31,028.231	4d		
3221.600	31,031.515	3d		
3220.759			31,039.618	4
3219.491	31,051.842	4b		
3218.229	31,064.019	3b		
3217.669	31,069.425	00		
3216.574	31,080.001	0b		
3216.043	31,085.133	5bbd		
3178.171			31,455.539	0
3176.863			31,468.489	2bd
3175.281			31,484.167	1b
3032.108			32,970.757	00
3031.605			32,976.228	1
3030.888	32,984.028	6		
3030.855			32,984.387	0
3030.402	32,989.318	5b		
3030.243			32,991.049	00
3029.964	32,994.087	4		
3029.736	32,996.569	4s		
3029.509	32,999.042	4s		
3029.313			33,001.177	6b
3029.104	33,003.454	3		
3028.773	33,007.060	3		
3028.614	33,008.793	5		
3028.321			33,011.987	4bd
3028.132	33,014.047	3		
3027.634			33,019.477	4d
3027.312			33,022.989	4s
3027.213	33,024.069	5b		
3007.018			33,245.848	00
3006.636			33,250.072	0d

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3006.285			33,253.954	0d
3005.830	33,258.987	3		
3005.701			33,260.414	00
3005.304	33,264.808	0		
3005.099			33,267.077	0
3004.586			33,272.757	6
3004.465	33,274.097	5b		
3003.636			33,283.280	4
3003.423	33,285.640	5		
3003.064	33,289.619	3		
3002.510	33,295.761	7		
3002.364	33,297.380	3d		
3002.003	33,301.384	1b		
3001.980			33,301.639	1
3001.597	33,305.888	5		
3000.337			33,319.875	3b
2999.996	33,323.662	2bd		
2999.399	33,330.294	2bd		
2990.011			33,434.940	5b
2989.566	33,439.917	4		
2989.051			33,445.678	4
2988.452			33,452.381	5s
2987.793	33,459.760	5		
2961.422			33,757.701	5d
2959.956			33,774.419	5
2959.731	33,776.987	5		
2958.810	33,787.500	6b		
2957.234	33,805.506	3		
2957.105			33,806.980	5
2956.315			33,816.014	5
2956.107	33,818.393	4		
2955.731			33,822.695	5
2955.670	33,823.393	4		
2955.355	33,826.998	3		
2954.495			33,836.844	6b
2954.428	33,837.611	00		

(Cont.)

Table 5-13

B(I) = 8.5kA	$\underline{\sigma}$		$\underline{\pi}$	
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3669.273	27,245.595	6s		
3669.260			27,245.692	3b
3669.003			27,247.600	3
3669.989	27,247.704	0		
3668.547	27,250.987	2		
3667.946			27,255.452	0
3667.670			27,257.503	7s
3667.656	27,257.607	2bd		
3666.946			27,262.885	8
3666.918	27,263.093	4		
3666.628			27,265.249	4
3666.611	27,265.375	8b		
3666.271			27,267.904	4
3666.229	27,268.216	8s		
3665.972			27,270.128	6
3665.934	27,270.411	5		
3665.528			27,273.431	6b
3665.511	27,273.557	4		
3664.927			27,277.903	0
3664.649			27,280.121	6
3664.621	27,280.181	0		
3664.065			27,284.320	3
3663.741	27,286.733	0		
3663.736			27,286.771	3
3663.029			27,292.037	4
3662.970	27,292.477	6		
3662.639			27,294.943	4
3662.636	27,294.965	6		
3662.081			27,299.102	6s
3662.042	27,299.393	6s		
3661.724			27,301.763	6s
3661.698	27,301.957	6		
3659.331			27,319.617	2d
3659.313	27,319.751	4bd		
3658.664	27,324.597	3bd		
3658.412			27,326.479	2d
3658.067	27,329.056	2b		
3657.699	27,331.806	3b		
3657.697			27,331.821	0d
3657.399			27,334.048	6
3657.362	27,334.324	2		
3656.571			27,340.237	00
3656.486	27,340.873	4b		
3655.944	27,344.926	7bd		
3655.630			27,347.275	6b
3655.595	27,347.536	3d		
3654.805			27,353.448	3b
3574.830			27,965.374	2
3574.621	27,967.009	3		

	σ		π		(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I	
3573.880	27,972.807	3			
3573.744			27,973.872	3	
3572.786	27,981.372	0			
3532.251			28,302.469	0	
3531.582			28,307.830	4s	
3531.357	28,309.634	8			
3531.341			28,309.762	4s	
3530.666			28,315.174	9s	
3530.454	28,316.874	8d			
3530.251			28,318.503	8b	
3530.197	28,318.936	3d			
3529.874			28,321.527	8	
3529.612			28,323.629	2bd	
3529.589	28,323.814	8b			
3529.198			28,326.952	2	
3528.961			28,328.854	1	
3528.937	28,329.047	7			
3528.748			28,330.564	7	
3528.666	28,331.222	7s			
3528.465			28,332.836	9b	
3528.429	28,333.125	7b			
3528.145	28,335.406	3bd			
3527.774	28,338.386	1d			
3527.442			28,341.053	9	
3527.167	28,343.262	10bb			
3527.030			28,343.262	8bd	
3526.793	28,346.268	10b			
3526.745			28,346.654	8bd	
3525.000	28,360.686	4bb			
3524.832			28,362.037	8bbd	
3524.444	28,365.160	9bbbb			
3524.322			28,366.142	8bbd	
3523.605			28,371.914	6b	
3523.585	28,372.075	8b			
3523.401			28,373.556	6b	
3523.326	28,374.160	5bd			
3521.938			28,385.342	5	
3521.883	28,385.785	6			
3521.637			28,387.768	5	
3521.579	28,388.236	4			

Table 5-14

B(I) = 9kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
4012.070	24,917.745	4bd		
4011.469	24,921.479	4d		
4011.175	24,923.305	4d		
4010.882			24,925.126	1b
4010.301	24,928.737	4		
4010.126			24,929.825	1b
4009.608	24,933.045	3bd		
4009.084			24,936.304	3bd
4008.883	24,937.554	6		
4007.849	24,943.988	7		
4007.128	24,948.476	1		
3904.885			25,601.696	4d
3903.596	25,610.150	2bd		
3902.743			25,615.747	8
3902.497	25,617.362	2b		
3902.133	25,619.751	1		
3901.934			25,621.058	7
3901.414			25,624.473	7bd
3901.041			25,626.923	0
3900.948	25,627.534	6		
3899.858	25,634.697	1		
3899.298			25,638.378	3
3898.729			25,642.120	3
3898.217			25,645.488	5
3897.694			25,648.929	5bd
3897.657	25,649.172	00		
3896.170	25,658.961	0		
3895.684	25,662.162	0bd		
3894.430	25,670.425	0b		
3893.852	25,674.235	0b		
3893.513			25,676.471	0
3892.386			25,683.905	1
3892.169	25,685.337	0		
3891.874			25,687.284	0
3891.819	25,687.647	2b		
3890.371	25,697.207	3		
3890.132			25,698.786	00
3889.818	25,700.861	3b		
3885.292	25,730.799	0		
3833.068	26,081.363	0		
3832.542			26,084.942	4
3831.994	26,088.672	1bd		
3831.321			26,093.255	5
3831.296	26,093.425	3d		
3830.782	26,096.926	2		
3830.593			26,098.214	4
3830.114			26,101.477	4
3829.429			26,106.146	6

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3829.202	26,107.694	6		
3828.735	26,110.878	2		
3394.176	29,453.777	0bd		
3392.360	29,469.544	1bd		
3391.733	29,474.992	2bb		
3391.149			29,480.067	5
3390.909	29,482.154	2bb		
3389.720	29,492.495	3		
3389.408	29,495.210	3		
3388.111	29,506.500	5s		
3269.035	30,581.251	7s		
3268.665			30,584.713	7s
3268.269	30,588.418	8s		
3267.767			30,593.117	8
3267.331	30,597.200	8s		
3267.136	30,599.026	3d		
3266.204	30,607.757	10		
3265.362	30,615.649	5ss		
3265.142			30,617.712	8s
3265.119	30,617.927	8		
3263.873			30,629.616	9
3263.610			30,632.084	2bd
3226.693	30,982.537	2		
3226.256	30,986.733	2d		
3223.957	31,008.829	6s		
3223.722	31,011.090	5s		
3223.611			31,012.157	0
3223.401	31,014.178	5		
3223.233			31,015.794	00
3222.589			31,021.992	3
3221.878	31,028.838	5s		
3221.542	31,032.074	4		
3220.584			31,041.304	4b
3219.312	31,053.569	4d		
3218.139	31,064.887	5bd		
3216.372	31,081.953	6bd		
3215.948	31,086.051	6bd		
3176.666			31,470.441	1b
3175.874			31,478.288	0
3175.092			31,486.041	1
3032.340			32,968.235	1
3031.717			32,975.009	1
3031.134	32,981.352	6s		
3031.001			32,982.799	1
3030.353	32,989.851	6b		
3029.802	32,995.851	6b		
3029.490	32,999.249	6		
3029.208			33,002.321	6
3029.149	33,002.963	4		
3028.722	33,007.616	5		
3028.443	33,010.657	5		
3028.191			33,013.404	4b
3027.947	33,016.064	5		

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I (Cont.)
3027.398			33,022.051	3
3027.150			33,024.756	5
3027.042	33,025.934	6bb		
3006.790			33,248.369	0
3006.218			33,254.695	00
3005.797	33,259.352	3b		
3004.956	33,268.660	00		
3004.490			33,273.820	6d
3004.346	33,275.415	5b		
3003.823	33,281.208	0		
3003.507			33,284.709	6
3003.454	33,285.297	6		
3002.889	33,291.559	3d		
3002.379	33,297.214	7		
3002.112			33,300.175	0
3001.808	33,303.548	2		
3001.500	33,306.965	5		
3001.186	33,310.449	0		
3000.212			33,321.263	4s
3000.136	33,322.107	2bd		
2999.317	33,331.206	2bd		
2990.074			33,434.236	5b
2989.692	33,438.507	0		
2989.421	33,441.539	1		
2988.951			33,446.797	4
2988.289			33,454.206	6
2987.695	33,460.857	4		
2961.445			33,757.438	3d
2959.874			33,775.355	5
2959.776	33,776.473	4b		
2958.778	33,787.866	5		
2957.254	33,805.277	00		
2957.193			33,805.974	5s
2956.262			33,816.620	5s
2956.103	33,818.439	3		
2955.798			33,821.929	5
2955.639	33,823.748	3		
2955.318	33,827.422	0		
2954.969	33,831.417	00		
2954.440			33,837.474	5bb
2954.375	33,838.218	0		

Table 5-15

B(I) = 9.6kA

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3669.435	27,244.393	3s		
3669.296			27,245.425	00
3669.023			27,247.452	1
3667.579			27,258.179	8s
3667.576	27,258.202	2s		
3666.816	27,263.851	2s		
3666.771			27,264.186	9s
3666.491			27,266.268	4bd
3666.485	27,266.312	8d		
3666.073			27,269.377	5
3666.059	27,269.481	7s		
3665.736			27,271.883	5ss
3665.534	27,273.386	2s		
3665.527			27,273.438	6s
3664.647	27,279.987	0		
3664.638			27,280.054	6d
3664.124			27,283.881	00
3663.996	27,284.834	0		
3663.710			27,286.964	1
3663.677	27,287.210	1		
3662.833			27,293.497	5s
3662.815	27,293.631	6s		
3662.427			27,296.523	5s
3662.403	27,296.702	6s		
3661.950			27,300.078	6s
3661.896	27,300.481	6s		
3661.526			27,303.240	6s
3661.493	27,303.486	6s		
3659.361			27,319.393	1b
3659.274	27,320.042	5d		
3659.666	27,324.582	3bd		
3658.571			27,325.292	1b
3658.032	27,329.318	2b		
3657.603	27,332.523	5d		
3657.531			27,333.061	2
3657.259			27,335.094	8d
3657.179	27,335.692	4b		
3656.310	27,342.189	5bd		
3655.841			27,345.696	00
3655.796	27,346.033	8bd		
3655.445			27,348.659	8bd
3655.423	27,348.823	4bd		
3654.574			27,355.177	1b
3654.267	27,357.475	00		
3574.922			27,964.654	1
3574.686	27,966.500	2d		
3573.964	27,972.111	2d		
3573.788			27,973.527	3s
3572.662	27,982.344	2d		

(Cont.)

λ_{air}(Å)	$\underline{\sigma}$ $\tilde{\nu}_{vac}$(cm^{-1})	I	$\underline{\pi}$ $\tilde{\nu}_{vac}$(cm^{-1})	I
3531.734	28,306.612	0		
3531.701			28,306.876	3
3531.457	28,308.832	9		
3531.441			28,308.960	3s
3530.863	28,313.594	2s		
3530.840			28,313.779	8ss
3530.584	28,315.832	8s		
3530.517			28,316.369	2bb
3530.211	28,318.823	2b		
3530.188			28,321.294	2bd
3529.903	28,321.294	2bd		
3529.872			28,321.543	9s
3529.519			28,324.375	2b
3529.508	28,324.464	9bb		
3529.250			28,326.534	2d
3528.948			28,328.958	1
3528.905	28,329.303	6s		
3528.661			28,331.262	6b
3528.584	28,331.881	8bd		
3528.234			28,334.691	8b
3528.224	28,334.771	3bb		
3527.687	28,339.084	2b		
3527.366	28,341.663	2b		
3527.346			28,341.824	8b
3527.002	28,344.588	9bb		
3526.727	28,346.798	9bd		
3526.712			28,346.919	7bb
3525.277	28,358.457	2bb		
3525.193			28,359.133	4bd
3524.832			28,362.037	7bd
3524.793	28,362.351	8b		
3524.618			28,363.759	8bb
3524.574	28,364.114	8b		
3524.263	28,366.416	8bb		
3524.176			28,367.317	8bb
3523.730	28,370.907	5bd		
3523.592			28,372.018	5b
3523.590	28,372.034	5bd		
3523.355	28,373.927	4bb		
3523.305			28,374.329	5d
3521.854	28,386.019	6d		
3521.758			28,386.793	3d
3521.485	28,388.993	3		
3521.413			28,389.574	4

Table 5-16

B(I) = 10kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3395.707	29,440.498	00		
3392.840	29,465.375	0		
3391.038	29,481.032	0		
3390.957			29,481.737	5
3389.600	29,493.539	2		
3389.282	29,496.306	2		
3387.997	29,507.493	4b		
3269.141	30,580.260	4s		
3268.638			30,584.965	8s
3268.394	30,587.249	6s		
3267.658			30,594.138	9b
3267.233	30,598.117	6s		
3266.112	30,608.619	8		
3265.420	30,615.105	3ss		
3265.144			30,615.693	7b
3265.066	30,618.424	7		
3264.523	30,623.517	0		
3263.769			30,630.592	9
3263.455			30,633.539	0b
3227.795	30,971.960	00		
3226.906	30,980.492	1		
3223.698	31,011.320	3		
3223.500	31,013.225	1		
3223.322	31,014.938	1		
3223.034			31,017.709	2b
3222.314			31,024.640	2b
3222.218	31,025.564	00		
3221.858			31,029.030	1b
3221.697	31,030.581	2bb		
3221.357	31,033.856	2b		
3220.291			31,044.129	2
3219.093	31,055.581	2		
3217.993	31,066.297	1b		
3217.373	31,072.283	0		
3217.231			31,073.655	00
3216.048	31,085.084	4b		
3180.586	31,431.655	0		
3178.485			31,452.431	1b
3174.973			31,487.221	1
3174.036			31,496.516	0
3032.444			32,967.104	0
3031.761	32,974.531	0		
3031.712			32,975.064	1b
3031.131	32,981.384	5s		
3031.097			32,981.754	2b
3030.366	32,989.710	5		
3029.748	32,996.439	5		
3029.352	33,000.752	5ss		
3029.104			33,003.454	6

	I		II	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3028.590	33,009.055	4		
3028.225	33,013.033	4		
3028.038			33,015.072	4
3027.733	33,018.397	3s		
3027.193			33,024.287	2d
3026.947			33,026.971	3
3026.866	33,027.855	4		
3006.737			33,248.955	2
3006.070			33,256.332	2
3005.679	33,260.658	3b		
3005.127			33,266.767	2
3004.990	33,268.284	2		
3004.244			33,276.544	5
3004.138	33,277.718	4bb		
3003.368	33,286.250	4b		
3003.361			33,286.327	5
3002.262	33,298.512	6b		
3001.354	33,308.585	4d		
3000.067			33,322.873	1
3000.048	33,323.084	1bb		
2999.213	33,332.361	1b		
2990.126			33,433.654	2bb
2989.729	33,438.094	1		
2989.321	33,442.657	1		
2988.928			33,447.054	3s
2988.251			33,454.631	4s
2987.562	33,462.347	2s		
2959.868	33,775.423	2b		
2958.745	33,788.242	3b		
2957.412	33,803.471	00		
2957.106			33,806.969	2
2956.509	33,813.795	0		
2956.185			33,817.501	2
2955.995	33,819.675	0		
2955.830			33,821.562	2
2955.604	33,824.148	0		
2955.243	33,828.280	1		
2954.889	33,832.333	1		
2954.289			33,839.203	1b
2954.175	33,840.509	00		

Table 5-17

B(I) = 10.7kA

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3669.555	27,243.502	3s		
3669.335			27,245.135	00
3669.097			27,247.036	2
3667.867	27,256.039	1		
3667.506	27,258.722	3b		
3667.501			27,258.759	8ss
3666.785			27,264.082	9s
3666.678	27,264.877	2bb		
3666.395			27,266.982	3bd
3666.342	27,267.376	8		
3666.133			27,268.930	3
3666.127	27,268.975	4		
3665.969			27,270.150	3
3665.907	27,270.611	6s		
3665.530			27,273.416	7d
3665.502	27,273.624	5bd		
3664.574			27,280.531	6s
3664.050			27,284.432	00
3663.741			27,286.934	0
3662.674	27,294.682	6s		
3662.663			27,294.764	4s
3662.218			27,298.081	4s
3662.203	27,298.192	6s		
3661.791			27,301.264	5s
3661.763	27,301.473	5		
3661.306			27,304.880	5s
3661.302	27,304.910	5		
3659.381			27,319.243	2b
3659.230	27,320.371	5bd		
3658.647	27,324.724	2bb		
3658.583			27,325.202	2b
3658.002	27,329.542	2bb		
3657.506	27,333.248	5bd		
3657.083			27,336.410	8s
3657.048	27,336.671	2bb		
3656.227	27,342.809	3b		
3655.704			27,346.721	1b
3655.661	27,347.043	7bd		
3655.267	27,349.990	2b		
3655.212			27,350.402	7bd
3654.339			27,356.936	1b
3575.131			27,963.019	00
3574.790	27,965.687	2s		
3574.072	27,971.305	2s		
3573.888			27,972.745	3s
3572.770	27,981.498	1		
3531.876	28,305.474	0		
3531.791			28,306.155	5

	σ		π		(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I	
3531.541			28,308.159	5	
3531.521	28,308.319	7			
3531.063	28,311.991	00			
3531.016			28,312.367	6s	
3530.672	28,315.126	7			
3530.484			28,316.634	4b	
3530.224	28,318.719	2bd			
3530.160			28,319.232	8b	
3529.924	28,321.126	2			
3529.853			28,321.695	8	
3529.448	28,324.945	9bb			
3529.394			28,325.379	2b	
3529.198			28,326.952	2b	
3528.841	28,329.817	7bd			
3528.813			28,330.042	5bd	
3528.713	28,330.845	5			
3528.500			28,332.555	3	
3528.497	28,332.579	8s			
3528.247	28,334.587	3bb			
3528.113			28,335.663	7bd	
3527.640	28,339.462	00			
3527.278	28,342.370	2			
3527.221			28,342.828	7bd	
3526.807	28,346.155	9bbb			
3525.914			28,353.334	7bb	
3525.428	28,357.243	2b			
3525.302			28,358.256	1b	
3524.875			28,361.692	7bd	
3524.816	28,362.166	8bd			
3524.354	28,365.884	9bb			
3524.149			28,367.534	8bbb	
3524.019	28,368.581	9bd			
3523.546	28,372.389	6bb			
3523.544			28,372.405	4b	
3523.226			28,374.965	4bd	
3523.194	28,375.223	5b			
3521.637	28,387.768	5			
3521.590			28,388.147	2	
3521.190			28,391.372	4d	
3521.182	28,391.436	3d			

Table 5-18

B(I) = 11kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3394.394	29,461.886	0		
3392.803	29,465.696	0		
3391.876	29,473.749	1		
3391.170	29,479.885	1		
3390.774			29,483.328	5
3389.491	29,494.487	3s		
3389.258	29,496.515	3s		
3387.846	29,508.808	5		
3269.259	30,579.156	4s		
3268.680			30,584.572	8
3268.524	30,586.032	6s		
3267.624			30,594.456	9
3267.410	30,596.460	2		
3267.161	30,598.792	5s		
3266.038	30,609.312	8		
3265.374	30,615.536	2ss		
3265.212			30,615.055	5s
3265.012	30,618.931	8		
3264.573	30,623.048	00		
3263.672			30,631.502	8b
3263.396			30,634.843	1
3227.200	30,977.670	0		
3226.615	30,983.286	0		
3223.569	31,012.561	5s		
3223.368	31,014.495	5s		
3223.209			31,016.025	3b
3222.310			31,024.678	3
3221.639	31,031.140	2b		
3221.255	31,034.839	2		
3220.116			31,045.816	4
3219.892	31,047.975	0		
3219.592			31,050.868	2b
3218.876	31,057.775	1		
3218.049	31,065.756	1b		
3216.034	31,085.220	6		
3215.217			31,093.118	1bb
3181.134	31,426.241	00		
3180.507	31,432.436	1bb		
3178.163			31,455.618	0
3176.522			31,471.867	1b
3174.894			31,488.005	1b
3032.663			32,964.724	0
3031.826			32,973.824	1b
3031.231	32,980.296	5s		
3031.176			32,980.895	2b
3030.394	32,989.405	6		
3029.856	32,995.263	5		
3029.711	32,996.842	5		

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3029.575			32,998.323	1b
3029.348	33,000.795	6s		
3028.974			33,004.870	7
3028.560	33,009.381	4		
3028.153	33,013.818	5		
3027.891			33,016.674	5
3027.684	33,018.932	4s		
3026.920			33,027.265	2
3026.756	33,029.055	5b		
3026.685			33,029.830	3
3006.930			33,246.821	2
3005.977			33,257.361	2b
3005.764	33,259.717	2bb		
3005.258			33,265.317	3
3005.002	33,268.151	00		
3004.186			33,277.187	5
3004.107	33,278.062	4ss		
3003.917	33,280.167	4ss		
3003.465	33,285.175	4		
3003.307			33,286.926	5
3002.608	33,294.675	2		
3002.203	33,299.166	6		
3001.302	33,309.162	5		
3000.148	33,321.974	1bb		
2999.955			33,324.117	1b
2999.207	33,332.428	1bb		
2990.164			33,433.229	2bb
2989.926	33,435.891	00		
2989.217	33,443.821	1		
2988.841			33,448.028	3
2988.141			33,455.863	3
2987.448	33,463.623	3		
2959.931	33,774.704	2d		
2959.770			33,776.542	4b
2958.692	33,788.848	3		
2957.133			33,806.660	1b
2956.566	33,813.143	0		
2956.148			33,817.924	3
2956.030	33,819.274	00		
2955.916			33,820.578	3
2955.643	33,823.702	1		
2955.209	33,828.669	1		
2954.200			33.840.223	3b

Table 5-19

B(I) = 11.8kA

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3669.699	27,242.433	4s		
3669.338			27,245.113	0
3669.111			27,246.798	1s
3667.745			27,256.946	1
3667.419	27,259.369	3		
3667.380			27,259.658	7s
3666.695	27,264.751	4b		
3666.654			27,265.056	8s
3666.186			27,268.536	5bd
3666.176	27,268.610	8bd		
3665.762	27,271.690	7ss		
3665.745			27,271.816	3
3665.536			27,273.371	5s
3665.508	27,273.580	4		
3665.305			27,275.090	4ss
3664.473	27,281.283	1		
3664.468			27,281.320	5s
3663.956			27,285.132	0
3663.601			27,287.776	1
3662.514	27,295.875	6s		
3662.493			27,296.031	5
3661.972	27,299.914	6s		
3661.951			27,300.071	5s
3661.582			27,302.822	6s
3661.572	27,302.897	5s		
3661.044	27,306.834	5s		
3661.042			27,306.849	6s
3659.245			27,320.259	00
3659.167	27,320.841	5bd		
3658.679	27,324.485	4b		
3658.636			27,324.806	3b
3657.945	27,329.968	1b		
3657.394	27,334.085	5bd		
3657.192			27,335.595	1b
3656.887			27,337.875	8bd
3656.878	27,337.942	2b		
3655.998	27,344.522	2b		
3655.493	27,348.300	6bd		
3655.487			27,348.344	1
3654.999	27,351.996	2b		
3654.942			27,352.422	7bd
3653.931			27,359.990	1
3574.930	27,964.592	2bd		
3574.104	27,971.504	2b		
3573.684			27,974.341	4s
3572.573	27,983.041	2bd		
3531.976			28,304.672	4
3531.955	28,304.841	2		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	σ I	π $\tilde{\nu}_{vac}(cm^{-1})$	π I
3531.626			28,307.477	4
3531.573	28,307.902	8		
3531.204			28,310.860	5s
3531.202	28,310.876	2		
3530.797	28,314.123	7s		
3530.774			28,314.308	2
3530.588			28,315.800	4
3530.176	28,319.104	2b		
3530.160			28,319.232	7bd
3529.890	28,321.399	2		
3529.844			28,321.768	7bd
3529.326	28,325.924	9bb		
3528.971			28,328.774	3bd
3528.859	28,329.673	6bd		
3528.388	28,333.454	8		
3528.368			28,333.615	3b
3527.933	28,337.108	1b		
3527.929			28,337.141	8b
3527.134	28,343.527	0		
3527.080			28,343.961	8bd
3526.042	28,352.305	9bb		
3525.922			28,353.270	8
3535.567	28,356.125	2bbd		
3525.558			28,356.197	8bd
3524.970			28,360.927	6bb
3524.879	28,361.659	6bd		
3524.251			28,366.713	7bb
3524.197	28,367.148	8bb		
3523.651	28,371.543	8bbb		
3523.647			28,371.575	7bb
3523.160	28,375.497	5b		
3523.150			28,375.578	4bb
3521.474	28,389.082	5d		
3521.444			28,389.324	2b
3521.007	28,392.847	3		
3520.975			28,393.105	3bd

Table 5-20

B(I) = 12kA	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3394.332	29,452.424	00		
3393.741	29,466.235	0b		
3391.363	29,478.207	0b		
3390.591			29.484.919	5b
3389.340	29,495.801	2		
3389.094	29,498.334	2		
3387.678	29,510.272	4		
3269.310	30,578.679	3s		
3268.712			30,584.273	6s
3268.602	30,585.302	5s		
3267.563			30,595.027	8
3267.487	30,595.739	2bd		
3267.013	30,600.178	6s		
3265.890	30,610.699	9		
3265.343	30,615.827	2ss		
3265.296			30,616.268	5s
3264.868	30,620.281	9		
3264.464	30,624.071	0		
3263.657			30,631.643	9b
3263.374			30,634.299	0
3227.296	30,976.748	00		
3226.762	30,981.874	00		
3225.211	30,996.773	2		
3223.422	31,013.976	5s		
3223.222	31,015.900	3		
3223.151			31,016.583	3
3222.241			31,025.342	2
3221.612			31,031.400	0
3221.516	31,032.324	3		
3221.122	31,036.120	3		
3219.905			31,047.850	2
3219.561			31,051.167	2
3218.740	31,059.087	1b		
3218.411	31,062.262	0		
3217.901	31,067.185	1b		
3215.998	31,085.568	7s		
3215.249			31,092.809	1bb
3180.372	31,433.770	0		
3176.451			31.472.571	1
3174.829			31,488.649	1
3173.813			31,498.729	0
3031.859			32.973.465	1
3031.335			32,979.165	1
3031.225	32,980.361	5s		
3030.997			32,982.841	00
3030.418	32,989.144	5b		
3029.785	32,996.036	5		
3029.527	32,998.846	4		
3029.248	33,001.885	5		

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3028.856			33,006.156	5
3028.399	33,011.136	4		
3027.926	33,016.293	4		
3027.806			33,017.601	3s
3027.629			33,019.532	3s
3027.473	33,021.233	4		
3026.664			33,030.059	2s
3026.575	33,031.030	5		
3026.508			33,031.761	2s
3005.939			33,257.781	0
3005.814	33,259.164	3b		
3004.061			33.278.571	6b
3004.061	33,278.571	4		
3003.834	33,281.086	4		
3003.530	33,284.455	4		
3003.163			33,288.522	5
3002.424	33,296.715	2		
3002.158	33,299.665	6		
3001.248	33,309.761	5		
2999.809			33,325.739	1
2999.147	33,333.095	0		
2990.201			33,432.816	0
2989.058	33,445.600	2		
2988.792			33,448.576	2
2988.542	33,451.374	00		
2988.058			33,456.792	4
2987.363	33,464.576	2		
2961.625			33,755.387	0
2959.619			33,778.265	2b
2958.667	33,789.133	1		
2957.266			33,805.140	00
2956.307	33,816.106	0		
2955.989			33,819.743	1
2955.736			33,822.638	00
2955.610	33,824.080	0		
2955.070	33,830.260	00		
2954.173			33,840.532	1bb

Table 5-21

B(I) = 12.8kA	$\underline{\sigma}$		$\underline{\pi}$	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3669.798	27,241.698	3s		
3669.435			27,244.393	1
3669.198			27,246.152	1
3667.304			27,260.223	6s
3667.303	27,260.231	3		
3666.919	27,263.085	3		
3666.591			27,265.524	8s
3666.570	27,265.680	3		
3666.319	27,267.547	2		
3666.273			27,267.889	1
3666.080			27,269.325	5
3666.065	27,269.436	8bd		
3665.561	27,273.183	7s		
3665.556			27,273.223	6s
3665.089			27,276.698	1
3664.451	27,281.447	1		
3664.451			27,281.447	5s
3663.534			27,288.275	0
3662.362			27,297.007	5s
3662.340	27,297.171	6s		
3661.763	27,301.473	6s		
3661.761			27,301.487	5s
3661.443			27,303.859	5s
3661.432	27,303.941	5s		
3660.848			27,308.296	5s
3660.824	27,308.475	5s		
3659.156			27,320.923	2
3659.115	27,321.229	5d		
3658.751			27,323.947	2b
3658.684	27,324.448	3b		
3657.950	27,329.931	1bb		
3657.355			27,334.377	0
3657.347	27,334.436	6d		
3657.033			27,336.783	0
3656.767			27,338.772	7bd
3656.735	27,339.011	1b		
3655.763	27,346.280	1b		
3655.373			27,349.197	2b
3655.323	27,349.571	7bd		
3654.746	27,353.889	1b		
3654.713			27,354.136	7b
3654.749			27,361.353	1b
3575.030	27,963.809	3b		
3574.141	27,970.765	3d		
3573.788			27,973.527	3
3572.585	27,982.947	2b		
3532.090			28,303.759	4
3532.069	28,303.927	1		
3531.671			28,307.117	3

(Cont.)

	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3531.628	28,307.461	7s		
3531.382			28,309.433	5s
3531.341	28,309.762	0		
3531.925			28,313.097	2
3530.898	28,313.314	6		
3530.526			28,316.297	4s
3530.176	28,319.104	2bd		
3530.158			28,319.249	7
3529.898	28,321.334	2bd		
3529.887			28,321.423	7
3529.253	28,326.510	9bbb		
3529.103			28,327.714	6d
3528.747	28,330.572	2		
3528.295			28,334.201	4
3528.293	28,334.217	6bd		
3527.783			28,338.313	8b
3527.749	28,338.586	1bb		
3526.994			28,344.652	8bb
3526.944	28,345.054	2		
3525.837	28,353.953	8bb		
3525.773			28,354.468	8b
3525.326			28,358.063	8
3525.309	28,358.200	2		
3525.034			28,360.412	7
3524.943	28,361.144	4bd		
3524.258	28,366.657	7bd		
3524.127			28,367.711	9bb
3523.954	28,369.104	8bbd		
3523.464	28,373.049	8bb		
3523.448			28,373.178	8b
3523.085			28,376.101	3b
3523.016	28,376.657	6d		
3521.328			28,390.259	2d
3521.308	28,390.420	6		
3520.744			28,394.968	1
3520.718	28,395.178	2		

Table 5-22

B(I) = 13kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3392.726	29,466.365	00		
3390.576			29,485.049	5b
3389.207	29,496.959	2		
3388.996	29,498.795	2		
3387.515	29,511.692	4		
3269.361	30,578.202	4b		
3268.775			30,583.684	5ss
3268.741	30,584.002	5b		
3268.663			30,584.732	5ss
3267.616	30,594.531	4b		
3267.481			30,595.795	8
3266.887	30,601.358	6s		
3265.772	30,611.805	9		
3265.372			30,615.555	3bd
3265.313	30,616.108	4ss		
3264.748	30,621.407	9s		
3264.310	30,625.515	0		
3263.539			30,632.750	9
3263.316			30,634.843	1s
3226.905	30,980.502	00		
3225.184	30,997.033	1b		
3223.462	31,013.591	2s		
3223.462	31,015.438	5s		
3223.224			31,015.881	2b
3223.162	31,016.477	1s		
3222.235			31,025.400	2d
3221.460			31,032.864	1
3221.422	31,033.230	5		
3221.090	31,036.428	3		
3220.280			31,044.235	0
3219.702			31,049.808	2b
3218.548	31,060.940	2		
3218.250	31,063.816	1		
3217.736	31,068.778	1		
3215.996	31,085.587	7s		
3215.236			31,092.935	0
3180.147	31,435.994	1		
3178.362			31,473.452	2b
3174.681			31,490.117	2
3174.234			31,494.551	00
3031.849			32,973.574	1
3031.391			32,978.555	0
3031.341	32,979.099	5s		
3030.888	32,984.028	00		
3030.762			32,985.400	0
3030.349	32,989.895	3bb		
3029.864	32,995.175	4b		
3029.508	32,999.053	5s		

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3029.287			33,001.460	00
3029.236	33,002.015	5s		
3028.728			33,007.551	6
3028.387	33,011.267	4		
3027.814	33,017.514	4		
3027.739			33,018.332	4s
3027.546			33,020.437	4s
3027.365	33,022.411	4		
3026.484	33,032.023	4		
3026.425			33,032.667	2s
3026.270			33,034.359	2s
3005.866	33,258.589	1b		
3004.003	33,279.214	3		
3003.971			33,279.568	5b
3003.620	33,283.457	3		
3003.114			33,289.065	5
3002.418	33,296.782	4		
3002.070	33,300.641	5		
3001.169	33,310.638	4		
2999.726			33,326.661	0
2999.072	33,333.928	2		
2988.705			33,449.550	1
2988.544	33,451.352	00		
2987.932			33,458.203	1
2987.139	33,467.085	1		

Table 5-23

B(I) = 13.9kA

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3670.067	27,239.701	4s		
3669.195			27,246.175	2
3667.670			27,257.503	2
3667.313	27,260.156	4b		
3667.196			27,261.026	7s
3666.589	27,265.539	4b		
3666.505			27,266.164	9s
3666.045	27,269.585	9		
3665.952			27,270.277	2
3665.539			27,273.349	3s
3665.528	27,273.431	9s		
3665.396			27,274.413	2
3664.967	27,277.606	2b		
3664.807			27,278.796	2bd
3664.352	27,282.184	2b		
3664.320			27,282.422	5d
3663.887			27,285.646	3
3662.170			27,298.438	5s
3662.166	27,298.468	7s		
3661.528	27,303.225	7s		
3661.528			27,303.225	6s
3661.247			27,305.320	6s
3661.228	27,305.462	6s		
3660.587	27,310.243	6s		
3660.587			27,310.243	6s
3659.049	27,321.722	5b		
3658.899			27,322.842	1bbb
3658.714	27,324.224	2bb		
3657.861	27,330.595	00		
3657.238			27,335.251	1
3657.218	27,335.401	5		
3656.919			27,337.635	1
3656.578			27,340.185	6bd
3656.543	27,340.447	4b		
3655.600	27,347.499	1b		
3655.164			27,350.761	2b
3655.156	27,350.821	4b		
3654.515	27,355.618	2		
3654.493			27,355.783	5bd
3653.476			27,363.398	1bb
3575.058	27,963.590	2s		
3574.165	27,970.577	2s		
3573.760			27,973.746	3b
3573.575	27,975.195	0		
3572.529	27,983.385	0		
3532.171			28,303.110	4d
3532.147	28,303.302	2s		
3531.703	28,306.860	6bd		
3531.657			28,307.229	3

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3531.548			28,308.103	3
3531.262	28,310.395	0		
3531.000			28,312.496	0b
3530.972	28,312.720	5		
3530.572			28,315.928	3s
3530.531	28,316.257	0b		
3530.133			28,319.449	6s
3529.958			28,320.853	5
3529.938	28,321.013	4bb		
3529.846			28,321.752	5
3529.310			28,326.053	5s
3529.178	28,327.112	8bbd		
3529.116			28,327.610	4
3528.566			28,332.025	1
3528.515	28,332.435	3b		
3528.249			28,334.071	3b
3528.149	28,335.374	7bd		
3527.647			28,339.406	9bb
3527.608	28,339.719	3bd		
3526.844			28,345.858	9bb
3526.805	28,346.171	4bd		
3525.648			28,355.473	9bd
3525.641	28,355.530	10bbb		
3525.053			28,360.259	9bd
3524.979	28,360.855	6bd		
3524.201	28,367.115	4d		
3523.942			28,369.200	9bbd
3523.765	28,370.625	7b		
3523.276	28,374.563	7bb		
3523.207			28,375.118	8bbd
3522.886			28,377.704	0
3522.834	28,378.123	5bd		
3521.119			28,391.944	2bd
3521.103	28,392.073	6		
3520.550			28,396.533	2s
3520.534	28,396.662	3b		

Table 5-24

B(I) = 14kA

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	σ I	π $\tilde{\nu}_{vac}$(cm^{-1})	π I
3390.315			29,487.319	5b
3389.075	29,498.108	2s		
3388.772	29,500.745	2s		
3387.304	29,513.530	4		
3269.317	30,578.613	3b		
3268.873			30,582.767	2ss
3268.774	30,583.693	6d		
3268.734			30,584.067	2ss
3267.635	30,594.353	2b		
3267.429			30,596.282	8
3266.716	30,602.960	6s		
3265.541	30,613.971	8		
3265.470			30,614.636	3
3264.560	30,623.170	8		
3264.130	30,627.204	0		
3263.475			30,633.351	8b
3263.236			30,635.594	1s
3224.994	30,998.859	1b		
3224.580	31,002.838	00		
3224.040	31,007.944	1		
3223.482	31,013.398	3b		
3223.298			31,015.169	1
3223.087	31,017.199	5b		
3222.899			31,019.008	2
3222.204			31,025.699	2
3221.366			31,033.769	2
3221.274	31,034.656	4b		
3220.912	31,038.143	4b		
3220.413	31,042.953	2		
3219.902			31,047.879	00
3219.486			31,051.891	3s
3219.454	31,052.199	0		
3218.373	31,062.629	3		
3218.083	31,065.428	3		
3217.562	31,070.458	1		
3215.951	31,086.022	6		
3215.265			31,092.654	2bbd
3179.974	31,437.704	00		
3176.179			31,475.266	2b
3174.538			31,491.536	2
3032.014			32,971.780	00
3031.707	32,975.118	00		
3031.286	32,979.698	5s		
3030.749			32,985.541	0b
3030.412	32,989.209	5		
3029.373	33,000.523	5s		
3029.091	33,003.595	5s		
3028.636			33,008.553	6
3028.243	33,012.837	4s		

(Cont.)

λ_{air}(Å)	$\underline{\sigma}$ $\tilde{\nu}_{vac}(cm^{-1})$	I	$\underline{\pi}$ $\tilde{\nu}_{vac}(cm^{-1})$	I
3027.609	33,019.750	4		
3027.605			33,019.793	4s
3027.312			33,022.989	4s
3027.129	33,024.985	4		
3026.920			33,027.265	00
3026.274	33,034.315	4b		
3026.168			33,035.472	3d
3006.938			33,246.732	00
3006.871	33,247.473	0		
3005.827	33,259.020	2b		
3005.641			33,261.078	00
3004.746			33,270.985	00
3003.880	33,280.577	4		
3003.851			33,280.898	4b
3003.593	33,283.756	3b		
3003.022			33,290.085	2
3002.326	33,297.802	2		
3001.981	33,301.628	6b		
3001.056	33,311.892	4		
3000.211	33,321.274	00		
2999.527			33,328.872	1
2998.952	33,335.262	00		
2988.780	33,448.710	1b		
2988.647			33,450.900	1
2987.863			33,458.976	2s
2987.098	33,467.544	2b		

Table 5-25

B(I) = 15kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3670.068	27,239.694	4s		
3669.476			27,244.088	0
3669.268			27,245.632	1
3667.621			27,257.867	1
3667.236	27,260.729	00		
3667.124			27,261.561	7s
3667.092	27,261.799	1s		
3666.409			27,266.878	9d
3666.408	27,266.885	3bd		
3665.800			27,271.407	4
3665.751	27,271.772	9		
3665.562			27,273.178	5
3665.261			27,275.418	3s
3665.212	27,275.782	8s		
3664.683			27,279.719	2
3664.239			27,283.025	4d
3664.226	27,283.122	1		
3663.884			27,285.668	0
3663.275			27,290.204	00
3662.007			27,299.654	4
3661.975	27,299.892	6s		
3661.301			27,304.917	5s
3661.289	27,305.007	6s		
3661.079			27,306.573	5s
3661.057	27,306.737	5s		
3660.350			27,312.011	5s
3660.328	27,312.176	5s		
3658.960	27,322.387	6		
3658.890			27,322.909	3bb
3658.653	27,324.679	2b		
3657.120	27,336.133	6d		
3657.098			27,336.297	2
3656.778			27,338.690	0
3656.425			27,341.329	7bd
3656.390	27,341.591	4		
3654.973			27,352.190	1b
3654.936	27,352.467	6bb		
3654.269	27,357.460	2b		
3654.249			27,357.609	4bd
3653.084			27,366.334	00
3575.183	27,962.613	2s		
3574.165	27,970.577	2s		
3573.892			27,972.713	2
3573.652			27,974.592	2s
3573.551	27,975.383	1		
3572.361	27,984.701	1b		
3532.351			28,301.667	4
3532.267	28,302.341	2ss		

	σ		π	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3531.778			28,306.259	6s
3531.748	28,306.499	8s		
3531.387	28,309.393	00		
3531.118			28,311.550	0
3531.082	28,311.838	5		
3530.615			28,315.583	3ss
3530.602	28,315.687	00		
3530.088			28,319.810	7bd
3529.963	28,320.813	3bb		
3529.815			28,322.000	3b
3529.385			28,325.451	6d
3529.157	28,327.281	8bb		
3529.064			28,328.027	6d
3528.486			28,332.667	5b
3528.429	28,333.125	2b		
3528.085	28,335.888	9		
3528.081			28,335.920	5b
3527.499			28,340.595	8bb
3527.473	28,340.804	3bb		
3526.737			28,346.718	8bb
3526.666	28,347.289	3bb		
3525.532			28,356.409	8bd
3525.508	28,356.599	8bbb		
3525.178			28,359.254	7
3524.925	28,361.072	3bbb		
3524.813			28,362.190	9bd
3524.101	28,367.920	3b		
3524.070			28,368.170	7b
3523.697			28,371.173	9bbd
3523.483	28,372.896	8bbd		
3523.039	28,376.472	8bbd		
3522.950			28,377.188	8bd
3522.696	28,379.234	6		
3520.987			28,393.009	2b
3520.330			28,398.307	4
3520.238	28,399.050	3		
3392.453	29,468.736	1		
3388.901	29,499.622	2s		
3388.675	29,501.589	2s		
3388.010			29,507.380	4b
3387.142	29,514.941	4		
3269.404	30,577.800	2		
3268.999			30,581.588	1ss
3268.906	30,582.458	4s		
3268.814			30,583.319	3s
3267.721	30,593.548	1		
3267.394			30,596.610	7
3266.571	30,604.318	4s		
3265.579			30,613.615	3
3265.437	30,614.946	7		
3265.185	30,617.309	4ss		
3264.465	30,624.061	7		
3263.995	30,628.471	0		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}(cm^{-1})$	I	π $\tilde{\nu}_{vac}(cm^{-1})$	I
3263.444			30,633.642	7b
3263.162			30,636.289	2
3224.855	31,000.195	2		
3223.549	31,012.754	3		
3222.951	31,018.508	5s		
3222.750			31,020.442	2
3222.148			31,026.238	1
3221.189			31,035.474	1
3221.174	31,035.619	4		
3220.806	31,039.165	3s		
3220.325	31,043.801	2		
3219.888	31,048.014	0		
3219.796			31,048.901	0
3219.281			31,053.868	2
3219.271	31,053.964	00		
3218.081	31,065.447	2bb		
3215.952	31,086.012	6		
3215.263			31,092.623	1bb
3179.926	31,438.179	1		
3176.103			31,476.019	2b
3174.442			31,492.488	2
3031.892			32,973.106	00
3031.386	32,978.610	5		
3030.440	32,988.904	5		
3030.327			32,990.134	00
3029.790	32,995.981	00		
3029.562	32,998.464	0		
3029.314	33,001.166	5s		
3029.109	33,003.399	5s		
3028.312			33,012.085	6b
3028.164	33,013.698	4		
3027.453	33,021.451	3		
3027.323			33,022.869	3
3027.985	33,025.465	4s		
3026.942			33,027.025	3
3026.127	33,035.920	4		
3025.694			33,040.647	4d
3005.905	33,258.157	3b		
3005.534			33,262.262	1
3005.432	33,263.391	0		
3003.771	33,281.284	4bb		
3003.717			33,282.382	5
3003.434	33,285.518	3		
3002.939			33,291.005	4
3001.912	33,302.394	6b		
3000.929	33,313.302	3		
3000.138	33,322.085	0		
2998.917	33,335.651	0		
2989.278	33,443.138	00		
2988.643	33,450.244	2b		
2988.578			33,450.971	2
2987.749			33,460.252	3s
2986.994	33,468.709	3		

Table 5-26

B(I) = 16kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3670.189	27,238.796	3		
3669.322			27,245.232	0
3667.562			27,258.306	5s
3667.469	27,258.997	1bb		
3667.000			27,262.483	7ss
3666.961	27,262.773	1bd		
3666.577	27,265.628	2		
3666.296			27,267.718	9s
3666.284	27,267.807	2		
3665.620	27,272.746	9bd		
3665.573			27,273.096	6bd
3665.057			27,276.936	3
3665.032	27,277.122	7ss		
3664.678			27,279.757	2
3664.398			27,281.841	1
3664.222			27,283.151	4s
3664.174	27,283.509	1		
3661.855			27,300.787	4
3661.820	27,301.048	6s		
3661.099			27,306.424	5s
3661.084	27,306.536	6		
3660.925			27,307.722	5s
3660.910	27,307.834	4		
3660.145			27,313.541	5s
3660.132	27,313.638	4s		
3658.945			27,322.499	2b
3658.897	27,322.857	5b		
3658.636	27,324.806	1bb		
3657.061			27,336.574	1
3657.033	27,336.783	7		
3656.597			27,340.043	0
3656.319			27,342.121	6d
3656.227	27,342.809	1b		
3655.848	27,345.644	00		
3654.835			27,353.223	2b
3654.776	27,353.665	6bd		
3654.040			27,359.174	4bd
3654.029	27,359.256	0		
3652.919			27,367.570	00
3575.167	27,962.738	1		
3574.209	27,970.232	1b		
3574.880			27,972.807	1
3573.635			27,974.725	2ss
3573.495	27,975.821	00		
3572.189	27,986.049	0		
3532.451			28,300.866	2
3532.399	28,301.283	3s		
3531.891			28,305.353	3b
3531.792	28,306.147	8s		

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3531.416	28,309.161	0		
3531.204			28,310.860	1
3531.132	28,311.437	2		
3530.636			28,315.415	6s
3530.559	28,316.032	00		
3530.046			28,320.147	9bd
3530.042	28,320.179	2bd		
3529.798	28,322.137	1		
3529.787			28,322.225	5s
3529.516			28,324.399	5
3529.045	28,328.180	10bbb		
3529.004			28,328.509	5
3528.552	28,332.137	1		
3528.399			28,333.366	5
3528.352	28,333.743	1		
3528.038			28,336.265	4
3527.985	28,336.691	9bd		
3527.862			28,337.679	2
3527.510	28,340.506	1		
3527.323			28,342.009	8bbd
3527.269	28,342.443	2b		
3526.725	28,346.819	2b		
3525.919			28,352.294	8bb
3525.906	28,353.399	3		
3525.546	28,356.294	8		
3525.382			28,357.613	6s
3525.162	28,359.383	8bb		
3525.152			28,359.463	5bd
3524.515			28,364.588	7b
3524.493	28,364.765	3b		
3524.070	28,368.170	3bd		
3523.999			28,368.742	6
3523.499			28,372.767	7bb
3523.346	28,373.999	8bb		
3522.777	28,378.582	8bd		
3522.675			28,379.404	7bd
3522.577	28,380.193	8bd		
3520.721	28,395.154	5d		
3520.652			28,395.710	0
3520.068			28,400.421	2d
3520.040	28,400.647	1		
3392.431	29,468.927	1b		
3389.964			29,490.372	6b
3388.780	29,500.675	3s		
3388.556	29,502.625	3s		
3386.961	29,516.519	5		
3269.506	30,576.846	2b		
3269.034			30,581.261	0
3269.003	30,581.551	3s		
3268.782			30,583.618	5
3267.839	30,592.443	1bd		
3267.306			30,597.434	7
3266.511	30,604.880	4s		

	$\underline{\sigma}$		$\underline{\pi}$	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I
3265.602			30.613.399	2ss
3265.323	30,616.015	7		
3265.168	30,617.468	1ss		
3264.358	30,625.065	7		
3263.913	30,629.240	1		
3263.337			30,634.646	7b
3263.095			30,636.918	1
3224.724	31,001.454	1		
3224.229	31,006.213	0		
3223.562	31,012.629	2		
3222.836	31,019.615	5		
3222.658			31,021.328	2
3222.133			31,026.382	0
3221.099	31,036.342	4b		
3221.059			31,036.727	2
3220.745	31,039.753	4		
3220.245	31,044.572	3		
3219.823			31,048.641	1bb
3219,812	31,048.747	0		
3219.164			31,054.997	3s
3219.082	31,055.788	1		
3217.995	31,066.277	3b		
3215.966	31,085.877	6s		
3215.322			31,092.103	1bb
3179.818	31,439.247	1		
3176.120			31,475.850	2b
3174.350			31,493.401	2
3031.436	32,978.066	5s		
3030.471			32,988.567	0
3030.467	32,988.610	4		
3029.705	32,996.689	3		
3029.434	32,999.859	0		
3029.219	33,002.201	5s		
3029.008	33,004.500	5s		
3028.445			33,010.635	5b
3028.085	33,014.559	3s		
3027.477			33,021.189	3
3027.286	33,023.273	3		
3027.022			33,026.153	3
3026.744	33,027.004	4		
3025.959	33,038.081	6b		
3025.751			33,040.025	4
3005.974	33,257.394	3		
3003.773	33,281.762	4		
3003.616			33,283.502	5
3003.347	33,286.483	4		
3002.836			33,292.147	4
3001.914	33,302.372	6		
3008.854	33,314.135	2		
2999.927	33,324.428	0		
2999.371			33,330.606	0b
2998.912	33,335.707	00		
2998.597			33,339.209	0b

	σ		π		(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}(cm^{-1})$	I	$\tilde{\nu}_{vac}(cm^{-1})$	I	
2988.556	33,451.217	3s			
2988.535			33,451.452	1	
2987.715			33,460.633	2	
2986.909	33,469.662	2b			

Table 5-27

B(I) = 17kA	σ		π	
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3670.282	27,238.105	1b		
3669.358			27,244.964	1
3667.539			27,258.477	2
3667.498	27,258.781	0		
3666.885			27,263.338	5s
3666.856	27,263.554	1		
3666.580	27,265.606	1		
3666.212			27,268.343	8s
3666.180	27,268.581	2		
3665.536			27,273.372	6bd
3665.469	27,273.870	9bd		
3664.901			27,278.097	2s
3664.838	27,278.566	6ss		
3664.636			27,280.069	2
3664.618	27,280.203	00		
3664.104			27,284.030	4b
3664.096	27,284.090	2b		
3661.670	27,302.166	4s		
3661.656			27,302.270	3
3660.848	27,308.296	5bd		
3660.820			27,308.505	5b
3659.919	27,315.228	2		
3659.914			27,315.265	4
3658.834	27,323.328	3d		
3658.638	27,324.791	1b		
3657.079			27,336.439	2bb
3656.968			27,337.269	1b
3656.943	27,337.456	6bd		
3656.111			27,343.677	6bd
3654.646			27,354.638	0
3654.252	27,357.587	3		
3653.764			27,361.241	4bd
3652.707	27,369.158	5bbd		
3652.614			27,369.835	00
3651.950	27,374.831	1bb		
3575.126	27,963.058	00		
3574.197	27,970.326	1d		
3573.848			27,973.058	0b
3573.467			27,976.040	1s
3571.984	27,987.655	00		
3532.570			28,299.913	2b
3532.513	28,300.370	2		
3532.074			28,303.887	2
3531.846	28,305.714	7		
3531.833			28,305.818	3
3531.494	28,308.535	0		
3531.295			28,310.131	0
3531.266	28,310.363	2		

	$\underline{\sigma}$		$\underline{\pi}$	(Cont.)
λ_{air}(Å)	$\tilde{\nu}_{vac}$(cm^{-1})	I	$\tilde{\nu}_{vac}$(cm^{-1})	I
3530.693	28,314.957	0b		
3530.656			28,315.254	2s
3530.054	28,320.083	0b		
3530.029			28,320.283	9bd
3529.687			28,323.027	6b
3529.403	28,325.306	1b		
3529.004	28,328.509	8bb		
3528.973			28,328.758	5d
3528.334			28,333.888	3
3527.926			28,337.165	3
3527.903	28,337.349	9b		
3527.649			28,339.390	1s
3527.216	28,342.869	3b		
3527.208			28,342.933	8b
3526.042	28,352.305	1s		
3525.846			28,353.881	8b
3525.810	28,354.171	1b		
3525.434	28,357.195	8		
3525.259			28,358.602	8bd
3524.934	28,361.217	8bb		
3524.174	28,367.333	5d		
3524.163			28,367.421	8bbd
3523.373			28,373.782	8bbd
3523.157	28,375.521	7bb		
3522.620			28,379.847	2
3522.488	28,380.910	7bb		
3522.398			28,381.635	8bd
3520.536	28,396.646	5d		
3520.530			28,396.694	1b
3519.824			28,402.390	1d
3519.806	28,402.535	1b		
3392.231	29,470.665	1b		
3389.816			29,491.660	6b
3388.651	29,501.798	3		
3388.384	29,504.123	3		
3386.817	29,517.773	5		
3269.538	30,576.547	2		
3269.118	30,580.475	3s		
3268.799			30,583.459	4
3268.059	30,590.384	00		
3267.226			30,598.183	7
3266.387	30,606.042	5s		
3265.653			30,612.921	2
3265.214	30,617.037	7		
3264.253	30,626.050	7		
3263.828	30,630.038	1		
3263.240			30,635.557	7
3262.986			30,637.942	2s
3224.589	31,002.752	2		
3223.620	31,012.071	2		
3222.683	31,021.087	5s		
3222.520			31,022.656	3
3222.114			31,026.565	1

(Cont.)

λ_{air}(Å)	σ $\tilde{\nu}_{vac}$(cm^{-1})	I	π $\tilde{\nu}_{vac}$(cm^{-1})	I
3220.975	31,037.536	4		
3220.925			31,038.018	1
3220.653	31,040.639	4		
3220.182	31,045.179	3		
3219.793			31,048.930	1
3219.655	31,050.261	00		
3219.432			31,052.411	2
3218.907			31,056.511	3
3218.903	31,057.514	0		
3217.905	31,067.146	4b		
3215.970	31,085.838	6		
3215.334			31,091.987	2bbd
3179.651	31,440.898	1		
3175.989			31,477.149	1b
3174.186			31,495.028	1b
3032.184			32,969.931	00
3031.455	32,977.859	5		
3030.930	32,983.571	0		
3030.461	32,988.676	4b		
3029.841	32,995.426	2b		
3029.337	33,000.915	2s		
3029.160	33,002.843	5s		
3028.963	33,004.990	5s		
3028.286			33,012.368	6b
3027.973	33,015.780	4s		
3027.333			33,022.760	4
3027.083	33,025.487	4		
3026.821	33,028.346	4		
3026.776			33,028.837	3
3025.786	33,039.643	5		
3025.453			33,043.279	4s
3005.938	33,257.792	3		
3005.382			33,263.945	2
3003.673	33,282.870	4		
3003.550			33,284.233	5b
3003.158	33,288.577	4		
3002.820			33,292.324	3
3001.772	33,303.947	5b		
3000.720	33,315.622	2		
2999.212			33,332.373	00
2998.816	33,336.774	00		
2988.425	33,452.684	0		
2987.562			33,462.347	3
2986.770	33,471.219	1		

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